Brussels, Belgium
BBRI offices

28-29 March 2012

International workshop

Achieving relevant and durable airtightness levels: status, options and progress needed

PROCEEDINGS

International Energy Agency
Energy Conservation in Buildings and Community Systems Programme

International workshop

Achieving relevant and durable airtightness levels: status, options and progress needed

Programme

First day, Wednesday March 28 2012

09:30-10:00 Introduction

10:00-11:15 Session 1: Philosophy and approaches regarding airtightness requirements: country views

11:30-13:00 Session 2: Philosophy and approaches regarding airtightness requirements: country views

13:00-14:00 Lunch (sandwiches)

14:00-15:30 Session 3: Durable airtightness performance: what we know and where we need to go

14:45-16:45 Session 4: Structured discussion: Pros and cons of various approaches for airtightness requirements - Recommendations and pitfalls to avoid

16:45-17:15 Inspiring experience

19.00 – 23.00

Walking dinner in the city centre (more practical information will follow

Second day, Thursday March 29 2012

09:00-10:40 Session 5: Dealing with airtightness in the construction process: reliable airtightness testing and reporting

11:00-12:30 Session 6: Dealing with airtightness in the construction process: reliable airtightness testing and reporting

12:30-13:15 Workshop conclusions

- *Highlights of the workshop and next steps within AIVC and TightVent* Peter Wouters / Rémi Carrié, INIVE, Int.

13:15 Lunch (sandwiches)

AIVC Newsletter
Air Infiltration and Ventilation Centre

Welcome to the new AIVC

Created in 1979, the Air Infiltration and Ventilation Centre now operates with a very new approach that was approved at the end of 2010. One key ambition of the new AIVC is to foster and/or coordinate projects resulting in different information tools (webinars, workshops, position papers, technical papers, ...) with an in depth review process and an increased impact of the dissemination of the information. 5 projects (shortly described in this newsletter) have already started with the approval the AIVC board (which replaces the previous AIVC Steering Group and is in charge of the overall policy and of approval of the projects and of their key deliverables).

We hope you enjoy our Newsletter to be informed on the progress of these projects as well as to learn about initiatives (publications, events, etc.) of interest to ventilation and infiltration specialists. Feel free to visit our website, which is a mine full of valuable information.

Peter Wouters, *Operating Agent AIVC*

no1
December 2011

In this issue

HealthVent, Health-Based Ventilation Guidelines for Europe

- Pawel Wargocki, Technical University of Denmark

Every European citizen has right to indoor air quality (IAQ) that does not endanger the health. This is implicit in the basic right to grow up and live in healthy environments. Recent EnVie project estimated in 2008 that the annual burden of disease (BoD) related to inadequate IAQ is 2 million disability adjusted life years (DALY) in EU27. Reducing this BoD is a high priority in the European health policies.

Ventilation is one of the methods to control IAQ including thermal conditions and humidity, structural moisture and mould growth, extraction and dilution of emissions from indoor sources and infiltration of ambient air pollution indoors. Ensuring optimal ventilation across the Member States is a key to reduce this BoD, to improve productivity and quality of life, and to remove associated social disparities between population groups and among Member States. At the same time, it is the key to meet the objectives of European energy conservation policies for buildings (Energy Performance of Buildings Directive, EPBD).

In 2009, EU's Executive Agency for Health and Consumers (EAHC) granted the project on Health-Based Ventilation Guidelines for Europe (HealthVent) within the EU's Health Programme 2008-2012; the Project was launched in mid 2010 and will run until the end of 2012. The aim of the project is to develop health-based ventilation guidelines reconciling health and energy impacts.

There are 11 partners in the project including experts from medicine, engineering, indoor air sciences, exposure assessment, energy evaluation and ventilation practices. They collect, survey and critically review the information that is necessary to develop the health-based ventilation guidelines. The guidelines are intended to be built on the experience, findings and recommendations of the previous projects funded by EC, the ongoing development of the WHO IAQ Guidelines and all projects relevant to the topic. Scientific data necessary to develop guidelines include the data on the effects of ventilation practices, techniques and rates on indoor air exposures and health, the data on the current ventilation regulations and standards, systems, practices and their performance in Europe, and data on the relationship between the existing ventilation strategies and technologies on the energy use in buildings.

The project will not only develop the guidelines but it will also discuss their consequences for health, using such indicators as reduction of DALY, for future trends in built environments, as well as for energy use in buildings, by establishing information necessary to continuously maintain EPBD implementation.

International Energy Agency
Energy Conservation in Buildings and Community Systems Programme

The project will also evaluate the possibilities and methodology for integrating IAQ in energy audits.

The guidelines are hoped to provide information necessary for policy makers, as well as all stake holders in building design, construction, operation and performance. The guidelines are hoped to help standardizing bodies and Member States in revising the existing ventilation codes and practices in ways that will reconcile increasing energy efficiency requirements with improved quality of life for European citizens.

At the end of 2012 the results of the project are intended to be presented at the workshop in Brussels. For further information see www.healthvent.eu.

Airtightness Workshop "Achieving relevant and durable airtightness levels: status, options and progress needed"

Brussels, 28-29 March 2012

AIVC TightVent Europe BUILDING AND DUCTWORK AIRTIGHTNESS PLATFORM

With the collaboration or support from:

International BUILDAIR Symposium REHVA VEA INIVE

The objective of this workshop is to bring key experts together to discuss three specific issues:

- The philosophy for setting airtightness requirements: recommendations and pros and cons of various approaches
- The durability of seals and bonds: what we know and where we need to go
- How to deal with airtightness in the construction process: lessons learnt and potential for quality management approaches.

More information and registration.

The AIVC-TightVent conference "Towards Optimal Airtightness Performance"

Brussels, 12-13 October 2011

AIVC conferences have been the major international events on air infiltration and ventilation for over 30 years. This year, AIVC has combined forces with the Building and Ductwork Airitghtness Platform (TightVent Europe — www.tighvent.eu), recently launched with the support of several institutes and industries. Over 160 participants attended the conference.

Next year's conference will be held in Copenhagen, 10-11 October 2012. Visit www.aivc.org for programme and registration information soon available.

Developing a Health Based US Ventilation Standard

- J.M. Logue ,M.H. Sherman, B.C. Singer Lawrence Berkeley National Lab

The Lawrence Berkeley National Lab's (LBNL's) has established the Healthy Efficient Homes (HEH) research program with the overarching goal of establishing a scientific basis for health-based ventilation standards that advances the mutually important objectives of a health-protective and energy-efficient U.S. housing stock. To achieve this goal, LBNL has undertaken a broad suite of research activities to indentify the hazards in the indoor environment, identify the potential impact of various pollutant mitigation strategies, and develop tools to determine what elements in a ventilation standard minimize health impacts in a cost efficient manner.

As a key early step LBNL sought to identify the pollutants or contaminants of highest priority, i.e. those that will drive ventilation requirements, and their sources. Results of this first stage of analyses revealed that, from the perspective of air pollutant exposures, acceptable residential indoor air quality cannot be robustly assured simply by setting a minimum overall ventilation or outdoor air exchange rate. In residences, the main drivers of non-biological air pollutant risk, excluding radon and SHS, are pollutant entry from outdoors (PM2.5, NO2, ozone), emissions from unvented combustion and cooking (NO2, acrolein, and PM2.5), and emissions from materials and consumer products (formaldehyde, acrolein). While material emissions are a major concern, removing pollutants from combustion and cooking and minimizing the infiltration of outdoor pollutants is also vital.

The major options for pollutant removal in the indoor residential environment fall into three broad categories: source reduction, air cleaning, and ventilation (general and task ventilation). From a review of available data sources, we determined that there is currently not sufficient information to reliably predict the effects on a residence level of using "low emitting" products and materials in home construction. However, calculating the potential energy savings from source control could be a

Achieving better envelope airtightness in practice: Recent Norwegian training and dissemination schemes
Wednesday 9 November 2011
10:00-11:30 Brussels, Oslo
Webinar recording soon available at www.tightvent.eu/events/recordings

Encouraging professionals to achieve better airtightness Recent French initiatives.
Check www.tightvent.eu for future announcement"

driving force for establishing and populating the necessary databases. We have conducted preliminary studies on the effectiveness of ventilation. Preliminary results suggest that emissions increase when gas phase concentrations are suppressed by ventilation; however the increase only partially detracts from the benefits of ventilation when air exchange rates are similar to the ASHRAE standard for central ventilation. Laboratory and field studies of range hood capture efficiency conducted by LBNL have indicated that capture efficiency varies widely (from less than 20% to nearly 100%) as a function of hood type, configuration, and which burners are used.

Maximizing the available pollutant removal options can lead to providing acceptable or good IAQ for a fraction of the cost. We are currently in the process of developing a data-driven, physics-based model to assess energy and indoor air quality health impacts across the U.S. population for both new and retrofitted homes. The goal of the modeling framework is to develop a computationally efficient modeling platform to determine the IAQ and energy impact of changes in residences that lead to changes in incremental airflow (i.e. adding ventilation, tightening homes, using local exhaust). The existing housing stock is varied and the impact of ventilation standards on that housing stock will be similarly varied. Model inputs will be distributions of home characteristics to represent the varied existing and new housing stock. The modeling effort will capitalize on existing data sources and previous research at LBNL and elsewhere. This framework will allow us to determine the population wide impact of widespread implementation of various ventilation standards on health and energy demand.

For more information, visit epb.lbl.gov

AIVC-TightVent projects on track

A key ambition of the new AIVC is to encourage projects with a high impact in terms of dissemination.
With approval of the description of their major steps and deliverables by the AIVC board, the following projects have started:

- Development and applications of air leakage databases
- Quality systems for airtightness requirements
- Philosophy for building airtightness requirements
- How tight and insulated ducts should be?
- Night ventilation for passive cooling

Within those projects, TightVent Europe together with the AIVC will play a key role in organizing or encouraging efforts in a consistent manner. We make use of our network of re-known specialists around the world and will put forward synergies between national initiatives.

Air leakage databases

On the subject of air leakage databases, a group of experts from Canada, the Czech Republic, France, Germany, Greece, the UK and the USA had an Internet meeting in June 2011 to discuss collaboration opportunities. The group agreed on three major deliverables (a standardized format for the output files of fan pressurization tests, a position paper on the need for structured air leakage databases, an overview of existing air leakage databases) as well as on the organization of workshops at the 2011 at 2012 TightVent-AIVC conferences.
Interesting links:
resdb.lbl.gov, Data from over 100 000 homes in the "Residential diagnostics database"
weatherization.ornl.gov,
Weatherization and Energy Program evaluation (USA)

Quality systems for airtightness measurements

Rewarding or imposing good airtightness in a regulation directly calls into question the reliability and accuracy of the measurements that are performed in practice. In several countries (e.g., DE, FR, UK), specific qualification schemes have been developed to address this issue.
This project reviews available schemes in this area and underlines the benefits but also pitfalls of such approach.

Airtightness requirements

Should there be specific airtightness requirements? If so, what level is to be required? Should there be a minimum level of air leakage? The objective of this project is to review critical aspects that have to be considered to tackle such questions.

A report is envisaged, which will be based on science and experience in the field. Main issues will be discussed in a topical session at the AIVC-TightVent conference.

Ductwork airtightness and insulation

The amount of energy involved in air transport in ductwork, if such system exists, represents a very significant amount of the total energy use of a low-energy energy building. Therefore, with nearly zero-energy as target, it becomes more and more critical not to waste energy because of excessive ductwork leakage or heat transmission losses. This project looks at how this issue is tackled in various countries, including in renovation. The programme is still under development and will be fine-tuned after the AIVC-TightVent conference, which included a specific session on this topic.

Ventilation for cooling

There are many research, demonstration and commercial activities related to the use of ventilation for cooling purposes. However, there is no structured communications between these activities and many scientific efforts are repeated without a real transfer of knowledge between them. This projects aims at sharing information on this subject, starting with a specific workshop at the AIVC-TightVent conference with re-known specialists on ground heat exchangers and heat island effect.

For more information about AIVC-TightVent projects

Please contact us at info@aivc.org

Air Infiltration and Ventilation Centre

Collaboration with TightVent

Both for the foreseen projects and the events in relation to airtightness, AIVC is combining forces with TightVent Europe (www.tightvent.eu), which is a newly-launched platform that focuses on airtightness of buildings and ductwork. TightVent Europe's main goal is to raise awareness on these issues that experience a revived interest with the recent trend towards nearly zero-energy buildings and to bring objective elements forward to ease the market transformation. Given the converging interests of both bodies, the AIVC Board and the TightVent Europe Steering Committee agreed to collaborate for instance for:

- the organization of the next conferences which will be joint AIVC-TightVent events;
- the overall scientific approach of TightVent and the implication of AIVC experts for scientific review of publications;
- the joint organization of four of the projects mentioned above.

TightVent receives support from the following organisations: European Climate Foundation, Buildings Performance Institute Europe, EURIMA, Lindab, Soudal, Tremco illbruck and Wienerberger.

Join the BUILD UP community on Energy efficient ventilation for healthy buildings

BUILD UP energy solutions for better buildings

Today, there is for many issues of interest not a lack of information but, at the same time, it is for most professionals difficult to easily find the information one is looking for.
BUILD UP (www.buildup.eu/)
is the official EU platform on energy efficiency in buildings, and INIVE is actively supporting this by facilitating a community on "Energy efficient ventilation for healthy buildings".

AIVC List of board members

Belgium
Arnold Janssens, *University of Ghent*
Jean Lebrun, *University of Liege*

Czech Republic
Miroslav Jicha, *Brno University of Technology*
Karele Kabele, *Czech Technical University*

France
François Durier, *CETIAT*
Pierre Hérant, *ADEME*

Germany
Hans Erhorn, *Fraunhofer Institute for Building Physics*
Heike Erhorn-Kluttig, *Fraunhofer Institute for Building Physics*

Greece
Mat Santamouris, *NKUA University of Athens*

Italy
Lorenzo Pagliano, *Politecnico di Milano*

Japan
Shigeki Nishizawa, *NILIM*
Takao Sawachi, *Building Research Institute*

Netherlands
Kees De Schipper, *VLA*
Wouter Borsboom, *TNO*

New Zealand
Manfred Plagmann, BRANZ

Norway
Peter Schild, *SINTEF Byggforsk*

Korea
Jae-Weon Jeong, *Sejong University*
Yun Gyu Lee, *Korea Institute of Construction Technology*

Sweden
Carl-Eric Hagentoft, *Chalmers University of Technology*
Paula Wahlgren, *Chalmers University of Technology*

USA
Andrew Persily, *NIST*
Max Sherman, *LBNL*

Operating agent
INIVE EEIG, http://www.inive.org, info@aivc.org
Peter Wouters, *operating agent*
Rémi Carrié, *senior consultant*
Samuel Caillou
Stéphane Degauquier

AIVC board guests
Morad Atif • José Maria Campos • Willem de Gids • Kirsten Engelund Thomsen • Maria Kolokotroni • Martin Liddament • Eduardo Maldonado • Bjarne Olesen • Paulo Santos • Hiroshi Yoshino

Representatives of organisations
Francis Allard, *REHVA*, www.rehva.eu
Jan Hensen, *IBPSA*, www.ibpsa.org

TightVent Europe
BUILDING AND DUCTWORK AIRTIGHTNESS PLATFORM

January 2012

Newsletter no2

A good start-up year for TightVent Europe

A major reason behind the launching of TightVent Europe was the need to increase communication, networking and awareness raising on airtightness since, for most countries, airtightness related issues represent major challenges for the wide-scale implementation of nearly zero-energy buildings.

Our achievements during this first year show that TightVent was really needed. These include the attendance to the webinars as well as to the joint AIVC-TightVent conference (over 160 participants) where 26 experts gladly accepted our invitation to give talks on specific topics such as the definition of airtightness requirements, quality systems, or the development of air leakage databases… We also have initiated several projects with key international experts and expected deliverables to be presented periodically in webinars, workshops and conferences in 2012 and beyond, … so stay tuned!

Peter Wouters, *Manager INIVE EEIG*

Regulatory requirements for ductwork leakage in Portugal: reasons behind and lessons learnt

- Based on presentation at the 2011 AIVC-TightVent conference by Eduardo Maldonado, University of Porto, Portugal

Ductwork airtightness is often considered to be an issue in cold or mild climates only in Europe, although there has been a significant amount of work in hot climates in particular in the US that demonstrates the great energy savings potential by reducing duct leakage.

One interesting exception is Portugal where mandatory requirements have been included in the regulation since 2006, as part of the implementation of the EU directive 2002/91/EC (EPBD). Requirements for new HVAC systems included for the first time a set of mandatory tests that must be carried out during commissioning, before the building receives its use permit. These requirements apply to buildings larger than 1000 m^2. The aim of the tests is to demonstrate that the installation is functioning as designed, in operational terms, but also meeting the minimum energy efficiency and indoor air quality (IAQ) targets set in the legislation.

Tests on the ventilation system include verifications of airflow rates, cleanliness, and airtightness. To pass the test on airtightness, ductwork leakage may not exceed 1.5 $l/s.m^2$ under a static pressure of 400 Pa. Air-tightness tests should be carried out using a procedure similar to that described in the AMA requirements* in Sweden.

It is too early to say if the new regulations have been successful: the data regarding the actual performance of the few buildings constructed with the new requirements has not been analyzed yet.

However, there is proof that the market adapted to the regulations. The share of pre-fabricated round ductwork with quality seals between ductwork components increased significantly (from less than 5% in 2006 to 30% in 2010). For rectangular ducts, the technology evolved to achieve better seals along duct sections and at unions between two consecutive sections, namely at the corners, representing now 20% of the market (extract ducts carrying air that is not recirculated, e.g., from toilets and wet-zones, are still usually low-quality ducts). Welded and screwed joints disappeared since then. In parallel, "a dozen" specialized companies now offer duct leakage testing services in the market (there were none in 2006).

* See for instance, Carrié, F.R., Andersson, J., and Wouters, P. 1999. Improving Ductwork - A Time for Tighter Air Distribution Systems, Report, EU Project SAVE-DUCT, Brussels 1999. ISBN 1902177104. Available at http://www.aivc.org/.

In this issue

TightVent Europe

BUILDING AND DUCTWORK AIRTIGHTNESS PLATFORM

Mark your calendar for two key AIVC-TightVent events

Airtightness Workshop "Achieving relevant and durable airtightness levels: status, options and progress needed"

Brussels, 28-29 March 2012

The objective of this workshop is bring key experts together to discuss three specific issues:

- The philosophy for setting airtightness requirements: recommendations and pros and cons of various approaches
- The durability of seals and bonds: what we know and where we need to go
- How to deal with airtightness in the construction process: lessons learnt and potential for quality management approaches.

More information and registration.

Optimising Ventilative Cooling and Airtightness for [Nearly] Zero-Energy Buildings, IAQ and comfort

Copenhagen 10-11 October 2012

The conference will include at least two tracks, one focusing to a large extent on ventilative cooling, and the other one to a large extent on airtightness issues.

More information to come at www.aivc.org and www.tightvent.eu

TightVent partner Soudal wins 'Entrepreneur of the year 2011' Award in Flanders, Belgium

With this award, the organizer Ernst & Young rewards successful Belgian companies for their outstanding growth and sense for innovation, entrepreneurship, strategy, sustainability and management.

You can find more info on this award on http://www.ey.hu/BE/nl/Home.

BUILDAIR International Symposium

Stuttgart, 11-12 May 2012

Information at http://www.buildair.de/homepage.html?Itemid=42
In collaboration with TightVent and AIVC.

Positive feed-back from the 1st Webinar

The first national webinar entitled "Airtightness and Ventilation perspectives in Romania: European context, regulation changes and progress needed" was held June 21.

Over 60 participants attended the meeting. Most attendees were from Romania but many parts of the world were represented. This made our discussions even more interesting.

The first two presentations were given by Peter Wouters and François Rémi Carrié on the European context, the reasons behind TightVent Europe, and the potential impacts of envelope and ductwork leakage.

Ioan Dobosi (REHVA) gave an interesting overview of the regulatory context in Romania with regards to ventilation and airtightness and insisted on the steps to be taken to reach NZEB targets.

Encouraging professionals to achieve better airtightness Recent French initiatives.
Check www.tightvent.eu for future announcement"

Missed the event?
All presentations are available on-line in pdf format. Soon you will be able to watch the recording of the event, and therefore listen to the presenters' speeches and discussions.

Webinar recordings:
www.tightvent.eu/events/recordings

Horia Petran gave very interesting information on the status and progress needed with detailed concrete data on energy performance and building stock at Romanian level but also from specific programmes and studies. He highlighted the bottlenecks, namely for the renovation of multi-family buildings from the Thermal Rehabilitation Program and for improving indoor air quality in educational buildings.

The main point highlighted within these presentations is that, with an annual heating energy use in a region of 100-300 kWh/m^2, over 8 million dwellings and 230 thousands of non-residential buildings, there exists significant room for improvement where ventilation and airtightness should play a major role, both to reduce energy use and avoid major mistakes resulting in degraded indoor air quality.

Growing awareness for the significance of air infiltration in American houses

- by Brett Welch, Knauf Insulation, North America

An increasing number of people within the building industry understand the impact that air infiltration has on the buildings being constructed. They understand the "house as a system approach" and realize that making upgrades to air sealing the building envelope can have a beneficial impact on the comfort, durability, indoor air quality and energy efficiency of a home while reducing the typical installed cost for HVAC equipment. Voluntary third party rating programs have adopted envelope tightness standards and many of them are becoming more stringent; some U.S. state building codes may even be updated to reflect the necessity to air seal.

The two most recognizable home certification programs in the U.S. are Energy Star and LEED for Homes. These are voluntary programs in which builders have an opportunity to differentiate their homes by means of energy efficiency upgrades. Each of their current iterations, Energy Star Version 2 and LEED for Homes 2008, have maximum envelope air leakage levels that must be met in order to be certified. The current levels of air sealing required for certification have been a fairly small hurdle. Those numbers will be getting a bit tighter with the new versions being introduced in 2012. Energy Star Version 3 will be rolled out January 2012 and LEED for Homes will implement their new guidelines later in the year. The new maximum air infiltration rates for each of those programs are listed in the following table.

Perhaps the most exciting new movement towards reducing infiltration rates is the new International Energy Conservation Code. IECC 2012 was designed to be a 30% energy efficiency improvement over IECC 2006, and requires that houses be verified by an approved third party to comply with maximum air leakage rates. The adoption of this standard into state government building codes is optional, however, it would mark the first time in the U.S. that infiltration commissioning would be mandatory, not just an element of voluntary programs.

An often overlooked aspect of home construction is the provision of mechanical ventilation. As building envelopes are made tighter, proper ventilation levels are vital to the health of occupants. The American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE) has developed standard 62.2-2010 to address indoor air quality and minimum ventilation rates in residential buildings. Following this guideline will ensure that once a house is "built tight" it will be "ventilated right."

Minimizing air infiltration is an essential step in building an energy efficient house, but the benefits of doing so extend well beyond increased energy efficiency. Proper air sealing can lead to increased comfort, improved indoor air quality and greater building durability. Builders should air seal houses as tightly as possible and ensure that adequate fresh air is provided through the use of controlled mechanical ventilation.

Climate zone	Maximum Air Leakage Rates (ACH_{50} or n_{50}) for the United States								
	Voluntary Programmes							IECC Codes	
	Energy Star V 2.0	Energy Star V 3.0	LEED for Homes 2008			LEED for Homes 2012		IECC 2009	IECC 2012
			Certified	2 Pts	3 Pts	1 Pt	2 Pts		
1-2	7.0	6.0	7.0	5.0	3.0	4.25	3.0	7.0 or visual inspection of air barrier	5.0
3-4	6.0	5.0	6.0	4.25	2.5	3.5	2.5		3.0
5-7	5.0	4.0	5.0	3.5	2.0	2.75	2.0		
8	4.0	3.0	4.0	2.75	1.5	2.0	1.5		

Climate Zones, 1 = semi-tropical and 8= extreme northern, for more information consult IECC

ISO 9972 revision status

- by Hiroshi Yoshino, Tohoku University, Japan

Given the revived interest for airtightness measurements throughout the world, the need for revision of ISO 9972 'Determination of air permeability of buildings — Fan pressurization method' has been approved as a new work item together with the revision of EN 13829. ISO TC163/SC1/WG10 is leading this work.

The current standard can be ambiguous with regard to the building preparation, which has been identified as a major source of discrepancy in recent reproducibility studies. In fact, this may depend on country-specific ventilation devices as well as on the calculation method in which the measurement result is used.

Another concern lies in the calculation of the building volume, floor area, or other building characteristics which are used to obtain the derived values (n_{50}, q_{p50}, w_{50}) and can be the source of major discrepancies.

Several other issues are examined, including uncertainties, averaging of several measurements, symbols, etc.

The revised standard should be distributed as a draft in April 2012.

TightVent Europe
BUILDING AND DUCTWORK AIRTIGHTNESS PLATFORM

Partners

TightVent is very pleased to welcome BlowerDoor GmbH and Retrotec, experts in air leakage measurement, as new members

Since 1989, **BlowerDoor GmbH** has been a pioneer in the fields of airtightness, especially airtightness measurements, and BlowerDoor product design in Europe. Synergies in engineering, product development and training have made the Minneapolis BlowerDoor a high quality device for air tightness measurements all over the world. BlowerDoor GmbH actively supports TightVent to achieve a good and durable quality in building air tightness as one important criterion to reach the ambitious goals of the Energy Performance of Buildings Directive (EPBD) recast.

Since 1980, **Retrotec** has pioneered the manufacture of advanced air permeability measurement equipment and analysis software. Retrotec has for many years been actively involved in the development of new standards for ISO and NFPA fire suppressant containment standards and large building testing standards for the US Army Corps of Engineers. With its renown experience and high-quality systems used in over 60 countries around the world, Retrotec looks forward to contributing its expertise to help reach TightVent's ambitious goals.

TightVent founding partners

The **Buildings Performance Institute Europe (BPIE)** is an independent, non-profit organisation based in Brussels. BPIE supports the development of ambitious but pragmatic building-related policies and programs at both EU and Member State levels. We timely drive the implementation of these policies by teaming up with relevant stakeholders from the building industry, consumer bodies, policy and research communities. With the TightVent Europe Platform, our ambition is to play a key role in implementing policies on building and ductwork airtightness, bearing in mind ventilation needs.

The **European Climate Foundation** aims to promote climate and energy policies that greatly reduce Europe's greenhouse gas emissions and helps Europe play an even stronger international leadership role in mitigating climate change. ECF supports the TightVent platform in its mission to create support for proper implementation of the new Energy Performance of Buildings Directive (EPBD) and to help policy makers, industry, developers and other stakeholders in the deployment of low-energy buildings.

Eurima is the European Insulation Manufacturers Association. Eurima members manufacture mineral wool insulation products. We actively support TightVent to develop knowledge and application of efficient airtightness solution for a successful implementation of the recast of the EPBD. This requires a good coordination between strong insulation and well-functioning ventilation in order to guarantee both energy efficiency and good indoor air quality.

INIVE is a registered European Economic Interest Grouping (EEIG) that brings together the best available knowledge from its member organisations in the area of energy efficiency, indoor climate and ventilation. INIVE strongly supports and acts as facilitator of TightVent Europe because it clearly fits within the objectives of our grouping, namely, fostering and structuring RTD and field implementation of energy-efficient solutions and good indoor climate in new and existing buildings.

Lindab is an international group that develops, manufactures, markets and distributes products and system solutions primarily in steel for buildings and indoor climate. With TightVent Europe, we learn more about the process of building airtight and energy efficient buildings; we fine-tune our product range by networking with suppliers confronted with the same issues. Our ambition is to transfer this knowledge all the way to building owners, architects/consultants, construction companies and workers.

Soudal NV is Europe's leading independent manufacturer of sealants, PU-Foams and adhesives. The company, established in 1966, proudly remains family owned. Soudal serves professionals in construction, retail channels and industrial assembly and has 45 years of experience with end-users in over 100 countries worldwide. Since sealing, bonding and insulating is our business, we actively support the Tightvent platform. And with 7 manufacturing sites on 4 continents and 35 subsidiaries worldwide, we hope to contribute to a wide-scale implementation of nearly-zero energy buildings.

Tremco illbruck has a leadership position in the sealants and building protection market throughout Europe, Africa and the Middle East. Our efforts are focused on Window, Façade, Coatings, Fire Protection, Insulating Glass and non-construction industries. Through TightVent Europe, we share our experience and expertise in the airtight connection of building components to reach ambitious goals and to improve knowledge of building professionals by implementing training programs in the EU.

Wienerberger is the world's largest producer of bricks and No. 1 on the clay roof tiles market in Europe with 245 plants in 27 countries. TightVent Europe enables us to further develop and optimize the sustainable building solutions we offer to our customers. Moreover, we want to transfer knowledge to our customers (both builders, renovators and building professionals such as architects, engineering agencies, contractors, etc.) by means of theory- and practice-oriented training courses, seminars, workbooks, etc.

If you are interested to become a partner, please contact us at **info@tightvent.eu**

Context, challenges and opportunities regarding airtightness

Peter Wouters, INIVE EEIG, Belgium

PHILOSOPHY AND APPROACHES FOR AIRTIGHTNESS REQUREMENTS IN THE NETHERLANDS

Willem de Gids[1], Wouter Borsboom[2],

1 VentGuide
Kievithof 3
2636EL Schipluiden
The Netherlands
ventguide@hetnet.nl

2 TNO
Van Mourik Broekmanweg 6
2628 XE, Delft
The Netherlands
wouter.borsboom@tno.nl

ABSTRACT

This paper describes the existing situation about air tightness and the consequent energy use in the Netherlands for existing and new buildings. It also discusses future developments.

KEYWORDS
Air tightness, ventilation, infiltration, air leakage, requirements, energy performance regulations.

INTRODUCTION
This paper describes the situation in the Netherlands regarding infiltration and air tightness in relation to the energy consequences.

PART 1; COUNTRY INFORMATION THE NETHERLANDS

Present situation
Requirements or measures in place for residential and non-residential buildings
Air tightness requirements in the Netherlands are stated for new buildings in the Building Regulations Dutch Building Degree 2003[1]. Requirements for air leakage in the Building Regulations are values which with normal building practice easily can be fulfilled. The requirements in the Netherlands are expressed in a flow at a pressure difference of 10 Pascal (q_{v10}), determined according to a Dutch Standard NEN 2686 [2]. For dwellings for instance the required value equals to an N_{50} of about 8. The real driver to build air tight nowadays is the assessment of air tightness in Dutch Energy Performance standards. Improved airtightness will be rewarded in the calculation of the Energy Performance Index. The current standards NEN 5128 [3] for dwellings and NEN 2916 [4] for utility buildings, will be replaced in mid-2012 by NEN 7120 [5]. This standards refers to a new standard for ventilation and infiltration namely NEN 8088 part 1[6]. These new standards NEN 7120 and NEN 8088 both address all buildings. All standards and regulation mentioned, are addressing whole building leakage. In the Building Regulations separate requirements are specified for ground floor leakage above crawl spaces NEN 2690 [7]. NEN 8088, Ventilation and infiltration for buildings - Calculation method for the supply air temperature corrected ventilation and infiltration air volume rates for calculating energy performance is brought in line with EN 15242 [8].

Requirements or measures as part of voluntary schemes or incentives
Voluntary schemes can be found for dwellings in NEN 2687 [9]. Depending on the type of ventilation systems, advised values are given on the bases of minimizing the influence of infiltration to ensure the proper functioning of the ventilation systems.

For systems with mechanical air supply the advised values are N_{50} of 2-3.
For normal standard dwellings with natural supply the advised value are N_{50} of 4-6

There is also a table for systems with natural supply where a minimal value for air tightness is given. The reason for this minimum requirements are to ensure the right direction of flow in natural extract ducting (overcoming back drafting) and for mechanical exhaust systems, the risk of overloading the fan, draft problems, noise problems and to high pressure differences. For typical Dutch houses this standard advice not to go to a lower value than a N_{50} of 2.

Background knowledge for air tightness requirements
All requirements are based on Dutch studies, sometimes even field studies. Also IAQ is being evaluated in some of these studies. Cooling has not been considered up to now.

Compliance framework
There is not a compliance framework, although there is an initiative of the Province of North Holland called Bouwtransparant. In the Netherland the municipality is responsible for the compliance of the Dutch Building Degree. The air tightness requirements are in most cases a consequence of the energy performance calculation. In practice it is not common practice that checks are made if this air tightness performance is achieved. It is not in all cases common practice that air tightness is checked if the other measures described energy performance calculation are actually realized in building. Bouwtransparant support the municipality with a methodology to comply the energy performance calculation in the design phase and the realization. Part of this method is a blower door test. In the cases that Bouwtransparant discovers to much air leakage the contractor repaired the building envelope up to desired air tightness level. There are also some initiatives to implement a quality control of the actual performance of newly built dwellings. Different organizations in the building industry are discussing what performance to measure. A blower door test can be part of such a quality control scheme. As an example we can take a set of new energy efficient dwellings which were monitored in a Dutch subsidy scheme. The aim of this subsidy scheme “Energysprong” was to reduce the energy performance of both installation and domestic appliances with 45%. An energy performance calculation based on NEN 5128 has been executed. An air tightness of N_{50} of 2 was required on the basis of the energy performance calculation, but N_{50} of 8 was achieved. The calculated primary energy consumption went up from 20.000 MJ/year up to 25.000 MJ/year.

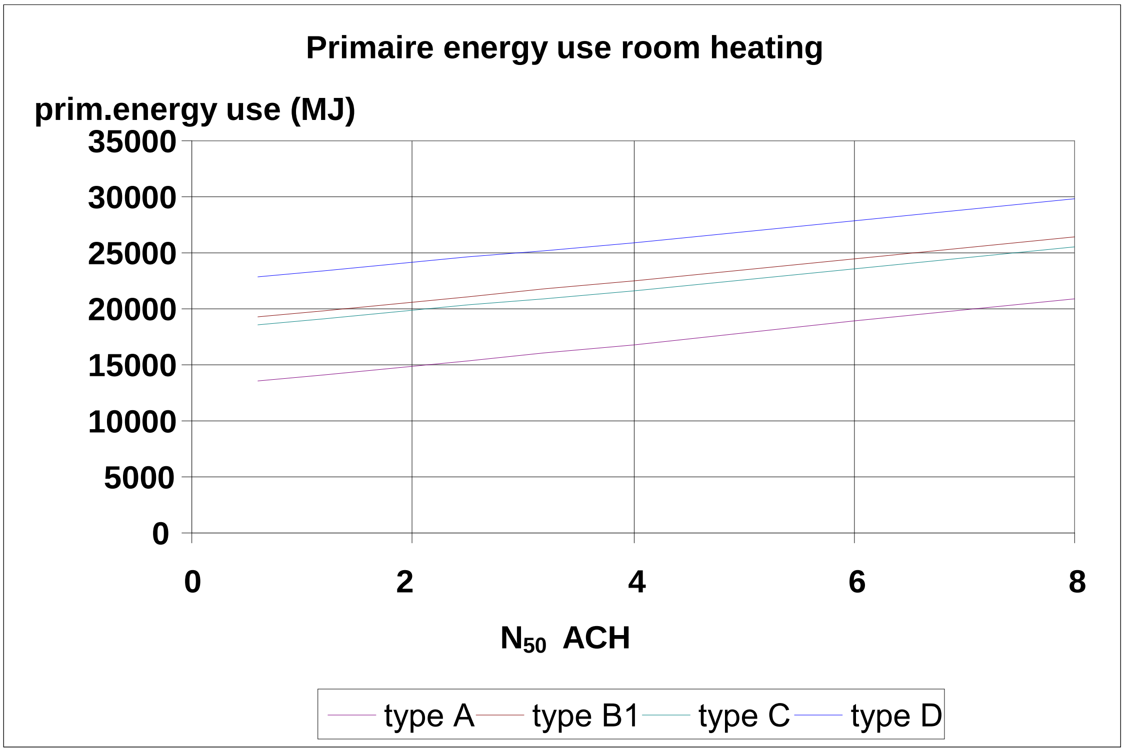

Figure 1. Energy consumption versus air tightness for four different houses

Expectation regarding future developments for new and existing buildings

Energy performance requirements are becoming more severe every couple of years. Through this there is a strong incentive to build more air tight. Nowadays this is only implemented for new buildings and not for existing buildings. The energy performance calculation in NEN 7120 [5] describes new buildings and existing buildings. Based on the demand of Europe on their member states, criteria are expected for energy performance of existing buildings in the Netherlands. Plans for those criteria are expected to be developed. If these are implemented, there is an increase expected of the air tightness in existing buildings where the air tightness level should be improved, because this can be an attractive measure to improve energy performance, comfort and indoor air quality.

PART 2; COUNTRY INFORMATION THE NETHERLANDS

Arguments in favour of specific requirements

The requirements in the Dutch building codes for maximum air tightness in buildings are very low. (N_{50} of about 8) It is possible with good building practice to easily improve the level of air tightness of new buildings. This is a measure without much additional costs. Studies indicates that a good building envelope is a measure which will lead in general to lower energy demand, where other measures the energy saving is more insecure and depending on the use. The building envelope has a long lifespan, which is expected to be more durable then installations. These are all arguments to make the requirements stricter. Ventilation systems with natural supply can achieve a higher under pressure, when airtightness is improved. This is important to guarantee indoor air quality in bedrooms at the leeward side.
Also there are arguments to set a minimum on the air tightness levels to ensure a minimum amount of air changes. People tend to use open combustion devices like stoves, heating

appliances, candles and when ventilation systems are bypassed a minimum amount of air changes can be ensured through ventilation and infiltration. For systems with natural supply there is a need to implement requirements minimal values for air tightness. The reason for this minimum requirement is to ensure the right direction of flow in natural extract ducting (overcoming back drafting) and for mechanical exhaust systems the risk of overloading the fan, draft, noise problems and to high pressure differences.

Arguments against specific requirements
The idea to set low maximum requirements for air tightness is to give architects, contractors and building developers more freedom to choose which measure they want to take. Some buildings systems are more air tight then others. And they have then the possibility to compensate that with other measures like well insulated windows, shutters or installations. The arguments against minimum requirements for air tightness is that air through the building enveloped is not defined and contaminations like mould grow can have a bad effect on the indoor air quality. Infiltration can have a strong effect on the air flows in case of demand flow ventilation and can bypass heat recovery.
To ensure indoor air quality in case of a very air tight building, minimum ventilation levels have to be guaranteed through the ventilation system in combination with heating systems.

Differentiate between general governmental requirements and requirements in the framework of incentives and/or voluntary schemes.
In case of maximum requirements for air tightness the governmental requirements should reflect what can be reach through good building practice. Requirements in the framework of incentives and/or voluntary schemes must give architect freedom in the measures they take. So the benefits of making a building more air tight can be exchanged to other measures. There are arguments to give a higher rating to measures which have a longer lifetime as the building envelope.

Do you see a need to improve the estimated impact of airtightness on heating and cooling use?
No arguments are foreseen.

What approach do you recommend to define airtightness requirements?
To define airtightness requirements different key issues have to be taken into consideration:

- the effect of local leakages on draft and thus comfort and energy use
- the effect of airtightness on the well-functioning of the ventilation system and air distribution.

Especially in the case of ventilation systems with natural supply and air tight building pressure differentials, noise and performance have to taken into consideration.

What level of airtightness performance do you recommend?
For systems with controlled natural supply and mechanical supply a study is needed to determine an optimal air tightness level taking into account: costs, energy saving and well functioning of the ventilation system. Not only the maximum allowed airtightness level are interesting but also minimum allowed air tightness level to ensure proper functioning of ventilation systems and indoor air quality. At last an important aspect is a well functioning quality framework to ensure the requirements will be met also in practise.

REFERENCES

[1] Dutch Building Degree 2003

[2] NEN 2686:1988/A2:2008 Air leakage of buildings - Method of measurement

[3] NEN 5128: 2004+A1:2009, Energy performance of residential functions and residential buildings- determination method

[4] NEN 2916: 2004+A1:2009, Energy performance of non-residential buildings - Determination method.

[5] NEN 7120; 2011/C2:2011, Energy performance of buildings - Determination method

[6] NEN 8088-1:2011/C1:2011, Ventilation and infiltration for buildings - Calculation method for the supply air temperature corrected ventilation and infiltration air volume rates for calculating energy performance

[7] NEN 2690 1991/A2:2008, Method of measurement of the specific air flow rate between crawl space and dwelling

[8] EN 15242: 2007 Ventilation for buildings — Calculation methods for the determination of air flow rates in buildings including infiltration

[9] NEN 2687:1989 Air leakage of dwellings - Requirements

PHILOSOPHY AND APPROACHES FOR AIRTIGHTNESS REQUIREMENTS IN GERMANY

Heike Erhorn-Kluttig*, Hans Erhorn

Fraunhofer Institute for Building Physics
Nobelstr. 12
70569 Stuttgart, Germany
** hk@ibp.fraunhofer.de*

ABSTRACT

This document describes the German philosophy for airtightness requirements which is presented at the AIVC-Tightvent workshop in Brussels, Belgium in March 2012. It refers to the German energy ordinance and the different standards that deal with airtightness and ventilation concepts in buildings. The requirements for different building types are compared and the necessary preparations for airtightness measurements listed. The general approach to airtightness is evaluated and arguments pro and con specific airtightness requirements are given.

KEYWORDS
Airtightness, requirements, Germany, energy ordinance, DIN 4108-6, DIN V 18599, KfW Effizienzhaus, Effizienzhaus Plus

1. INTRODUCTION

The ventilation rate in buildings is composed of several parts: Firstly, air changes due to the opening of windows or doors, due to possibly existing outdoor air apertures and exhaust air grilles, or due to mechanical ventilation systems with and without heat recovery and secondly, infiltration losses based on air leakages at the building envelope. While the first ones are intentional, the air changes based on infiltration rates are mostly unwanted because they can’t be controlled. However, the total air change rate has to secure the hygienically required minimum air change. In Germany several legal and technical documents exist that deal with ventilation issues in general and, more specifically, with airtightness requirements.

2. AIRTIGHTNESS REQUIREMENTS FOR BUILDINGS IN GERMANY

The German airtightness requirements are defined in a combination of a specific airtightness standard (DIN 4108-7, [1]) and the energy saving ordinance (EnEV, [2]) that determines which values for infiltration can be inserted in the calculation of the energy performance of buildings. In general, new buildings have to be constructed in a permanently airtight way according to the generally recognised codes of practice, as stated in the energy saving ordinance.

2.1 DIN 4108-7

The German standard DIN 4108-7:2011-01 “Thermal insulation and energy economy in buildings - Part 7: Air tightness of buildings - Requirements, recommendations and examples for planning and performance” defines requirements to the airtightness of heated or air-conditioned buildings and building components. The standard replaces the former version issued in August 2001 and contains the adaptation to current technical developments and the more precise formulation of the requirements for bondings (substrates/processing, etc.). It includes requirements, planning and performance recommendations as well as performance examples, including suitable construction products for compliance with requirements on the air tightness of heated or air-conditioned buildings and building parts. Numerous example sketches suggest solutions for developing airtight connections, for corner connections with plate materials, for connections in lightweight metal construction and for concrete, amongst others. Only principle sketches and example sketches are represented. They are not construction detail drawings and they do not represent other constructive or physical matters. Other solutions are permissible if the principle of air tightness is conformed to. The Committee responsible for this standard is Working Committee NA 005-56-93 AA "Luftdichtheit" ("Air tightness") at the Building and Civil Engineering Standards Committee (NABau).

The airtightness requirements of heated or air-conditioned buildings and building parts have been defined into more detail when being compared to the version of 2001. The previous standard (*DIN 4108-2001*) included the following requirements:

- If airtightness measurements are made, the measurements have to follow DIN EN 13892:2001-02, method A, and the air flow rate must not be higher than:
  - In buildings without mechanical ventilation:
    - 3.0 1/h related to the net volume of the building
    - 7.8 $m^3/(m^2h)$ related to the net floor area of the building
  - In buildings with mechanical ventilation:
    - 1.5 1/h related to the net volume of the building
    - 3.9 $m^3/(m^2h)$ related to the net floor area of the building
  - The volume related requirement applies in all cases. If a building has a clear storey height lower than 2.6 m, the net floor related area can be applied instead.
- For buildings with mechanical ventilation including heat recovery a significant reduction of the given air flow rate is advised.
- For the assessment of the building envelope the leakage rate of the building envelope must not be higher than 3.0 $m^3/(m^2h)$.

The new version of the standard (*DIN 4108-2011*) states at first that requirements to the airtightness are regulated in the actual version of the German energy ordinance. If no such requirements are included there, the air change rate measured at a pressure difference of 50 Pa (n_{50}) in new and existing buildings having undergone complete renovation of the building envelope must not exceed:

- 3.0 1/h for buildings without mechanical ventilation
- 1.5 1/h for buildings with mechanical ventilation.

In these values no changes have been implemented. But where the former standard did not imply that buildings have to be built/renovated according to these requirements, but merely stated that if airtightness measurements are realised these values have to be met, the new version of the standard clearly relates to the energy decree as main source and presents the values as general requirements for both new buildings and completely renovated buildings.

For buildings or building parts exceeding a volume of 1500 m³ the airtightness has to be assessed additionally by the building envelope leakage rate (q_{50}) which must not exceed 3.0 m³/(m²h). The standard also includes 4 remarks:

1. Even if the limits are met, local leakages in the airtightness layer are possible, which can lead to moisture problems due to convection. Appropriate design of construction details applies.
2. If the requirements for buildings with mechanical ventilation systems have to be met, in most cases the windows have to meet airtightness class 3 according to DIN EN 12207-1 [3].
3. If airtightness measurements of buildings or building parts are made, the air change rate must not exceed the maximum values given in table 1 under consideration of the described preparation of the building for the measurements.
4. Especially in buildings with mechanical ventilation with heat recovery air change rates lower than the given limits in the energy decree of 2009 are recommended.
5. With natural ventilation via self-regulating outdoor air apertures and with exhaust ventilation it is advised to differ from DIN EN 13829 [4] method A and to mask the outdoor air apertures during the measurement and therefore to go below the given limits of DIN EN 13829.

Table 1 of the standard lists recommended building preparation and recommended maximum air change rates for the airtightness measurement at 50 Pa pressure difference, which are copied to the table below:

Ventilation system		**Type of outdoor air aperture**	**Preparation of outdoor air aperture and exhaust air grilles**	**Maximum value $n_{50, max}$ [1/h]**
Natural ventilation	Via windows only		Not applicable	3.0
	Cross ventilation via outdoor air apertures	Not closable	No measures	3.0
		Closable, without self-regulation	Closure of outdoor air aperture	3.0
		With self-regulation	Sealing of outdoor air aperture	1.5
	Shaft ventilation	Not closable or no outdoor air aperture	No measures at outdoor air aperture, sealing of exhaust air grilles	1.5
		Closable, without self-regulation	Closure of outdoor air aperture, sealing of exhaust air grilles	1.5
		With self-regulation	Sealing of outdoor air aperture and exhaust air grilles	1.5
Mechanical ventilation	Exhaust system	Closable, without self-regulation	Sealing of outdoor air aperture	1.0
		With self-regulation	Sealing of outdoor air aperture	1.0
	Supply and exhaust system	-	Sealing of exhaust, exit, supply and outdoor air ducts	1.0

Table 1. Recommended building preparation and recommended maximum air change rates for the airtightness measurement at 50 Pa pressure difference according to DIN 4108-7:2011-01.

DIN 4108-7:2011-1 also deals with design and construction by listing requirements and recommendations in the two building phases. As main principle a circumferential air tightness layer (air barrier) is requested. This principle is further explained for some difficult component connections and construction types. Other recommended design details are included as text or as schemes which include component airtightness (brick and concrete components), air barriers, plaster or other boards, airtight joints with sealants, joints of air barriers, wood joints, metal joints and plastic joints. For the construction site some basic requirements are given, such as a reasonable organisation of the different work sections. It is also recommended to perform an accompanying surveillance check during the construction phase.

2.2 Energy saving ordinance (EnEV)

The German energy saving ordinance of 29 April 2009 sets minimum requirements for the energy performance of new buildings and existing buildings that are undergoing renovation. It applies to all buildings that are heated or cooled by using energy. In paragraph 6 the document deals with requirements to the airtightness and the minimum ventilation rate. Clause 1 requests that all buildings have to be constructed such that all building envelope parts, including the joints, will permanently remain airtight according to generally recognised codes of practice.

The air permeability of seals at exterior windows, glazed doors and roof-lights has to comply with the air permeability classes listed in table 1 of appendix 4. For buildings with up to 2 storeys proper the air permeability class of the window components has to be 2; for buildings with more than 2 storeys proper air permeability class 3 is required according to DIN EN 12207-1.

The ordinance also states that if the airtightness (total building envelope and window components) is verified, the proof of airtightness can be taken into account in the energy performance calculation of the building as long as the maximum values given in appendix 4 number 2 are met. Appendix 4 contains maximum air change rates for airtightness tests of the building envelope according to DIN EN 13829:2001-2 at 50 Pa pressure difference related to the heated or cooled air volume:

- For buildings without mechanical ventilation: 3.0 1/h
- For buildings with mechanical ventilation: 1.5 1/h.

Clause 2 of paragraph 6 requires that new buildings have to be constructed such as to ensure the minimum air change rate for health and heating purposes.

Thus the main requirements concerning airtightness in buildings are the same in the energy saving ordinance and the standard DIN 4108-7. The ordinance is the authoritative document and indicates that the main impact of the airtightness requirements is the possibility to use lower infiltration rates in the energy perfomance calculation - if the requirements are met and if there is a proof. The standard however advises to aim for lower air change rates (especially in the case of mechanical ventilation with heat recovery) and gives further information on how to test the airtightness of buildings. Also, some design details are given and it is emphasized that it is important to assure the correct implementation of all details on the construction site and a thorough planning of the different work sections.

2.3 Energy performance calculations

In Germany, the energy performance calculations for new buildings have to be performed by using the following calculation standards:

- For residential buildings:
  - DIN V 18599:2007-02 or alternatively
  - DIN-V-4108-6:2003-06 in combination with DIN V 4701-10:2003-08
- For non-residential buildings: DIN V 18599:2007-02

In both cases there is no fixed maximum primary energy use value but a comparison with a mirror building (in Germany so-called reference building) with a defined set of reference technologies. The result of the calculation of the mirror building with the set of reference technologies is used as a maximum primary energy demand for the real building (concept of the mirror baseline building).

As part of the reference technologies the airtightness is defined to:

- For residential buildings calculated with DIN V 18599-2: category I
  - For buildings without mechanical ventilation: n_{50}=2 1/h
  - For buildings with mechanical ventilation: n_{50}=1 1/h
- For residential buildings calculated with DIN V 4108-6: a building with a proof of the airtightness
  - For buildings without mechanical ventilation: average standard ventilation rate (infiltration + active ventilation) n=0.6 1/h
  - For buildings with mechanical ventilation: average infiltration rate n_x=0.2 1/h
- For non-residential buildings calculated with DIN V 18599-2: category I
  - For buildings without mechanical ventilation: n_{50}=2 1/h
  - For buildings with mechanical ventilation: n_{50}=1 1/h

From the n_{50}-value, DIN V 18599 derives an infiltration rate according to the following equation:

$$n_{inf} = n_{50} * e_{wind} * (1 + f_{V,mech} * t_{V,mech} / 24\ h) \quad (1)$$

where:

e_{wind}: wind shield coefficient (standard value: 0.07)

$t_{V,mech}$: daily operation time of the mechanical ventilation system

$f_{V,mech}$: factor to assess the infiltration rate based on balanced or not balanced ventilation systems

That means for natural ventilation and for balanced mechanical ventilation the infiltration rate is calculated to be 0.07 * n_{50}. A measured air change rate of 2.0 1/h at 50 Pa pressure difference results in an infiltration rate of 0.14 1/h. The measured air change rate has to be inserted in the calculation. If there is no measured rate available, the DIN V 18599 gives a list of default values that can be used instead.

Table 2 lists the alternative infiltration or ventilation rate values and compares them to the ones used as part of the set of reference technologies in order to show the impact of different airtightness values in the calculation.

Building type	Calculation method	With or without mechanical ventilation system	Category	Air change rate at 50 Pa pressure difference n_{50} 1/h	Average ventilation rate (infiltration + active ventilation) n 1/h	Average infiltration rate n_x 1/h
Residential buildings	DIN V 18599	Without	I: Airtightness test done + requirements met	**2**	-	-
			II: New buildings w/o airtightness test	4	-	-
			III: Cases that don't fit in I, II, IV	6	-	-
			IV: visible air leakages (e.g. open joints)	10	-	-
	DIN V 18599	With	I: Airtightness test done + requirements met	**1**	-	-
			II: New buildings w/o airtightness test	4	-	-
			III: Cases that don't fit in I, II, IV	6	-	-
			IV: visible air leakages (e.g. open joints)	10	-	-
	DIN V 4108-6	Without	Airtightness test done + requirements met	-	**0.6**	
			No airtightness test	-	0.7	
		With	Airtightness test done + requirements met			**0.2**
			No airtightness test*		0.7*	
Non-residential buildings	DIN V 18599	Without	I: Airtightness test done + requirements met	**2**	-	-
			II: New buildings w/o airtightness test	4	-	-
			III: Cases that don't fit in I, II, IV	6	-	-
			IV: visible air leakages (e.g. open joints)	10	-	-
	DIN V 18599	With	I: Airtightness test done + requirements met	**1**	-	-
			II: New buildings w/o airtightness test	4	-	-
			III: Cases that don't fit in I, II, IV	6	-	-
			IV: visible air leakages (e.g. open joints)	10	-	-

* in this case the calculation has to be performed without lower air change rates for the mechanical ventilation system. That means that in DIN V 41078-6 the ventilation losses have to be calculated as if the building had no mechanical ventilation system and no airtightness test. The auxiliary energy of the mechanical ventilation system however has to be included in the final and primary energy use of the building based on the calculation method specified in DIN V 4701-10.

Table 2. Infiltration rates and ventilation rates depending from the airtightness of buildings applicable in the German energy performance of buildings calculation. Marked in bold are the rates that have to be used as part of the set of reference technologies applied in the mirror baseline building.

The implementation of the different categories into a calculation tool based on DIN V 18599 is presented in figure 1:

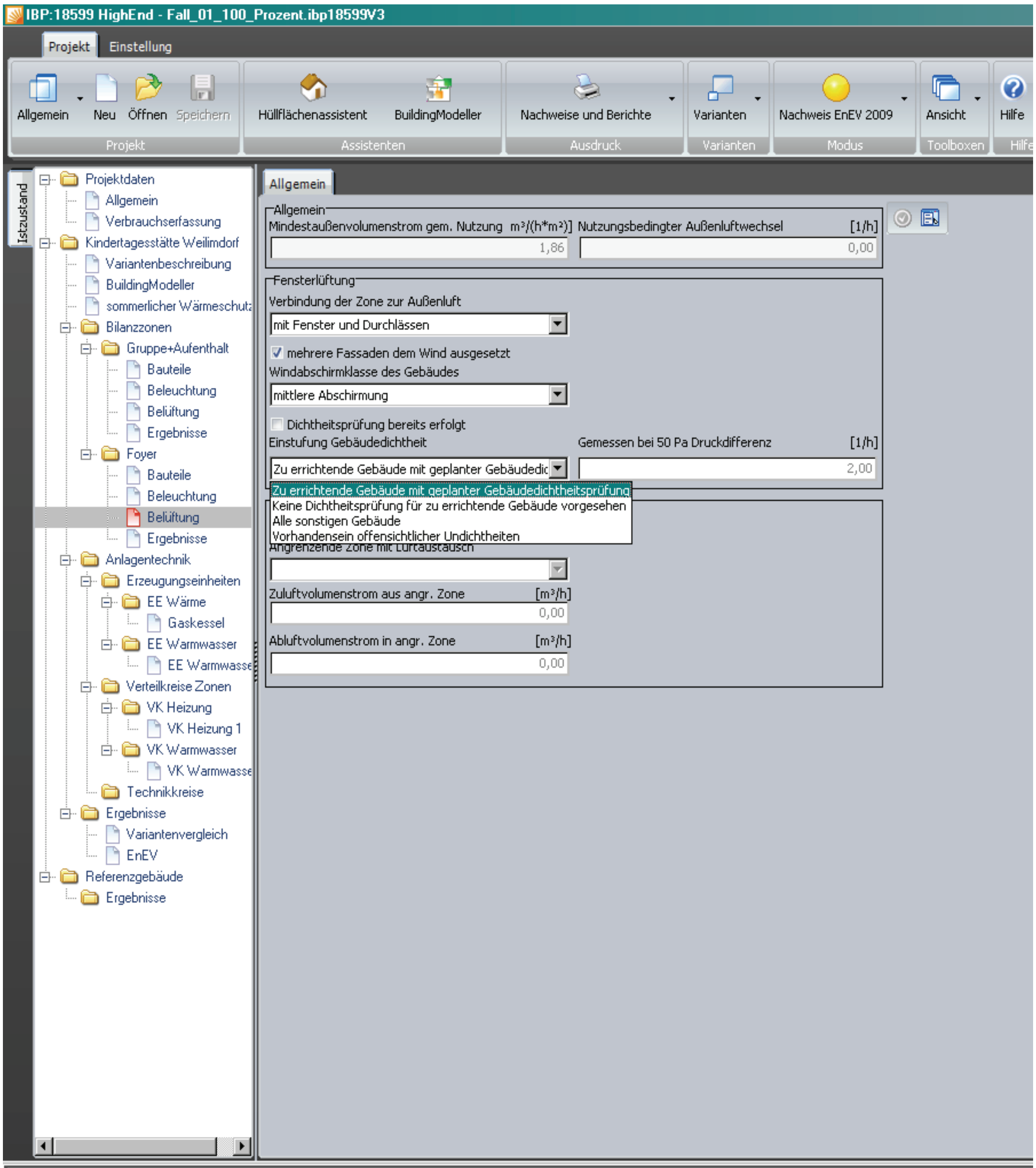

Figure 1. Implementation of the 4 different airtightness categories according to DIN V 18599 into the computer calculation tool ibp18599 [6].

2. REQUIREMENTS IN VOLUNTARY SCHEMES OR INCENTIVES

In Germany, several voluntary high performance buildings schemes exist. First of all there are several levels of the KfW Effizienzhaus [7] (KfW Efficiency House), ranging from KfW Effizienzhaus 70 (with a maximum primary energy demand of 70 % compared to the requirement in the energy ordinance for new buildings), to KfW Effizienzhaus 55 and KfW Effizienzhaus 40. For these types of new residential buildings, the state-owned KfW bank offers a loan at reduced interest rates. For the two most energy efficient ones (55 and 40), KfW bank also offers a repayment subsidy. Similar but slightly less efficient levels for KfW efficiency houses are valid for the renovation of existing residential buildings. However, there are no stricter requirements for those buildings concerning airtightness in place.

A well-known type of voluntary scheme is the passive house [8]. This type of buildings has been initially developed in Germany by the private organisation Passivhaus Institute. The passive houses are calculated with a procedure that differs from the national German energy performance calculation standard, also in the area of the ventilation losses. The net heating energy demand of these houses has to be 15 kWh/m²a or lower and the primary energy demand for heating, ventilation, domestic hot water and household electricity shall not exceed 120 kWh/m²a. Another requirement is that the infiltration rate at 50 Pa pressure difference has to be 0.6 1/h or lower. This is less than half of the required value for a regular German new residential building. Passive houses can also receive loans with lower interest rates from the KfW bank.

A rather new type of highly energy efficient building is the energy surplus house. In August 2011 the Federal Ministry of Transport, Building and Urban Development has started a specific funding programme for pilot dwellings that generate more energy that they annually use for heating, domestic hot water, ventilation, cooling, lighting and household appliances. The official name for these buildings is nowadays Effizienzhaus Plus [9] but will soon be renamed to KfW Effizienzhaus Plus as the state-owned bank is supposed to extend the current funding programme to a real market programme in the near future. No special airtightness requirements apply in addition to the standard requirements for all new buildings.

Figure 2. Photo of the Effizienzhaus Plus that was officially opened in Berlin in December 2011.

3. COMPLIANCE FRAMEWORK

Though various requirements for the airtightness have been defined in the energy ordinance and the DIN 4108-7 standard, there is no explicit compliance framework available. The strongest push towards realising an airtight building is the credit that is given in the energy performance calculation of the building. When a good airtightness value has been included in the calculation, this implies that the certifier has verified the documentation and the result of the airtightness test, which is available at the building owner. Otherwise the certifier would issue an incorrect energy performance certificate and could get a fine.

DIN V 4108-7 advises to perform an accompanying surveillance check on the construction site that includes airtightness. An airtightness test is however not explicitly requested.

The general building practice in Germany does not include an airtightness test for residential buildings. Most buildings are still built without a mechanical ventilation system and the energy performance calculation is then based on the somewhat higher infiltration rates. Fraunhofer Institute for Building Physics is involved in many pilot projects for high performance buildings, including both new constructions and building renovation. Here, a low infiltration rate is nearly always part of the energy concept and is also evaluated by blower door tests performed by the institute.

With the requirements for the primary energy use in building being more and more tightened, energy performance calculation credits for an airtight building are becoming attractive as the costs for an airtightness test along with a good building design and realisation have to be compared to expenses for additional insulation measures, even more efficient building service systems or renewable energy generation.

4. CONCLUSIONS AND FURTHER THOUGHTS

The German legislative approach towards airtightness in buildings is to generally demand permanently airtight buildings according to the commonly recognised codes of practice. The energy ordinance and its accompanying calculation codes target for a good airtightness by crediting a measured airtightness performance that is lower than 3.0 1/h (without mechanical ventilation systems) or 1.5 1/h (with mechanical ventilation system) with lower infiltration losses in the energy performance calculation. For mechanical ventilation systems with heat recovery even lower values are recommended. This is accompanied by presenting some exemplary solutions for designing the air barrier in building joints and by giving advice on how to prevent damages to the airtightness layer on the construction site.

As main arguments in favour of specific airtightness requirements are seen:

- The unnecessary ventilation losses and the consequently increased energy need for heating (and cooling). This is of even higher impact in mechanically ventilated buildings with heat recovery systems.
- The risk of structural damages occuring at the building envelope. Also here the damages will usually be bigger in buildings with mechanical ventilation systems, as the over- or underpressure (also in balanced systems as in one room there is usually supply and in another exhaust) tends to aggravate the situation.

There are also some arguments against specific airtightness requirements. These are mostly derived from experiences with renovations of existing buildings. Here it was found that in buildings that faced a major renovation at the façade, the air permeability of the window seals and the airtightness after the renovation were significantly improved. Though this was generally aimed for a problem came up as the building users (being the same before and after the renovation) did not adapt their ventilation behaviour to the lower infiltration losses. While before they did not need extensive and regular ventilation by for example opening the windows, the necessary hygienic air change rate was not achieved with the same window opening times. The apartments showed signs of moisture and mould. One possible solution is to use window sealings that include small openings or to integrate outdoor air apertures into the façade. This is kind of illogical: First we spend effort and money on a tighter building envelope and then we buy specific systems to increase the uncontrolled ventilation loss again.

Of course what would be necessary here is to adapt the ventilation behaviour. This can however be problematic in apartments where the user is absent (at work or similar) for extended periods of the day. A visualisation of the indoor air quality and the relative humidity of the indoor air can support the users in finding out when they should open the windows. Alternatively, mechanical ventilation systems that are controlled by the relative humidity of the indoor air and/or the indoor air quality can be helpful. One ventilation unit per apartment can usually fulfill the hygienic requirements.

The authors welcome the general approach to set specific requirements to the airtightness of new buildings and buildings that undergo major renovations. Especially for buildings with mechanical ventilation and even more for those that include heat recovery the airtightness requirements should be severe. On the other hand, the hygienically required minimum air change rate has to be secured at all times. DIN 1946–6 [10] requires the development of a ventilation concept that may include natural ventilation, visualisation and mechanical ventilation. The airtightness level of the building is one influence factor in the calculation of the ventilation concept. There should be definitely more checks regarding the compliance on site, just like checks of the airtightness levels used for the energy performance calculation.

5. REFERENCES

[1] DIN 4108-7:2011-01 "*Thermal insulation and energy economy in buildings - Part 7: Air tightness of buildings - Requirements, recommendations and examples for planning and performance*. Beuth Verlag (2011).

[2] Energy saving ordinance (EnEV) "*Verordnung zur Änderung der Energieeinsparverordnung*" of 29 April 2009. Bundesgesetzblatt (BGBl.) Jahrgang 2009 Teil I, Nr. 23, S. 954-989.

[3] DIN EN 12207-1 "*Windows and doors - Air permeability – Classification*". German version EN 12207:2000-6. Beuth Verlag (2000).

[4] DIN EN 13829 " *Thermal performance of buildings - Determination of air permeability of buildings - Fan pressurization method". (ISO 9972:1996, modified); German version EN 13829:2000*". Beuth Verlag (2001).

[5] DIN V 18599 "*Energy efficiency of buildings - Calculation of the net, final and primary energy demand for heating, cooling, ventilation, domestic hot water and lighting*". Beuth Verlag (2011).

[6] ibp18599 "*Energieeffizienzsoftware für die DIN V 18599*". (Energy efficiency software for the German standard DIN V 18599). Available at http://www.heilmannsoftware.de/ibp/produkte.

[7] KfW Effizienzhaus "*Effizienzhaus Förderung – Staatliche Förderprogramme für energieeffizientes Bauen und Sanieren*". Energiestandards - KfW Effizienzhaus 55 / 70 / 100 und Passivhaus. More information available at: http://www.effizienzhaus-foerderung.info/energiestandards/energiestandards-kfw-effizienzhaus-55-70-100-passivhaus/

[8] Passive house "*Passivhaus Institut - Passivhaus Projektierungs-Paket PHPP*". Available at: http://www.passiv.de/

[9] Effizienzhaus Plus "*Effizienzhaus Plus des Bundesministeriums für Verkehr, Bau und Stadtentwicklung*". More information available at: http://www.bmvbs.de/DE/EffizienzhausPlus/effizienzhaus-plus_node.html

[10] DIN 1946–6 "*Ventilation and air conditioning - Part 6: Ventilation for residential buildings - General requirements, requirements for measuring, performance and labeling, delivery/acceptance (certification) and maintenance*". Beuth Verlag (2009).

PHILOSOPHY AND APPROACHES FOR AIRTIGHTNESS REQUIREMENTS IN THE UK

Martin Liddament

VEETECH Ltd
7a Barclays Venture Centre
Sir William Lyons Road
Coventry
UK
CV$ 7EZ

ABSTRACT

Reducing the energy loss due to uncontrolled air infiltration is regarded as an important objective in the quest to construct zero carbon buildings. To overcome this, airtightness requirements have been steadily incorporated into the UK Building Regulations over the last 10 years. In this paper, the regulations are summarised and information is given on the airtightness requirements and testing procedure. Air tightness is specified in terms of air permeability per hour for each m^2 of envelope area $m^3/(h.m^2)$ at an induced pressure of 50 Pa.. In most instances, the highest permitted value is 10 $m^3/(h.m^2)$ at 50 Pa. However this invariably needs to be adjusted downwards to satisfy the design energy performance of the building. Maximum leakage values for future (2016) regulations is currently under review, with values of 3 $m^3/(h.m^2)$ being considered for air conditioned buildings and 5 $m^3/(h.m^2)$ for most other buildings.

Testing must be undertaken by an authorised tester using calibrated instrumentation. Registration and measuring procedures are governed by the Airtightness Testing and Measurement Association (ATTMA). All testing results must be recorded and made available to the Building Regulators. Exceptions to testing include very small housing developments (one or two dwellings) and commercial spaces up to 500 m^2 floor area. However an assumed leakage of $m^3/(h.m^2)$ at 50 Pa must be applied which means that additional improvements to the thermal properties to the building must be made to satisfy energy efficiency performance. Special arrangements also apply to very large and complex buildings that cannot be tested in entirety. These have to be surveyed and component tested by a qualified expert. The minimum allowance for permeability when using this approach is 5 $m^3/(h.m^2)$ at 50 Pa

KEYWORDS

UK Building Regulations, air permeability, airtightness philosophy, energy performance, ventilation, MVHR, compliance, testing.

INTRODUCTION

As the thermal insulation properties of buildings improve, air change accounts for an ever greater proportion of overall building heat loss. This can now account for 50 % or more of the total heating load. Thus, in the UK, much effort is being focused on improving ventilation performance. Air infiltration losses through adventitious openings have been identified as a particular problem for two principal reasons, i.e:

- Airflow is uncontrolled and can be particularly high in cold weather because of enhanced stack pressure;
- Air infiltration seriously impairs the performance of mechanical ventilation heat recovery systems.

For these reasons airtightness requirements have been steadily incorporated into the UK Building Regulations over the last 10 years. This is set to continue as efforts progress to introduce zero carbon or near zero carbon buildings from 2016 onwards.

This report summarises the relevant UK Building Regulations and associated aspects related to airtightness.

AIRTIGHTNESS REQUIREMENTS FOR UK BUILDINGS

Regulations

Compliance methods for Building Regulations for much of the UK are enshrined in a series of 'Approved Documents'. Aspects covering ventilation and airtightness (2010 edition) are contained in:

- Approved Documents Part F: Ventilation [1];
- Approved Document Part L1A: Conservation of Fuel and Power (New Dwellings) [2];
- Approved Document Part L1B: Conservation of Fuel and Power (New Buildings other than Dwellings) [3].

These are all freely available and downloadable using the links given in the references. Currently revised regulations for airtightness are being proposed for implementation in 2016. The proposals are included in a consultative document [4] with comments required by the end of March 2012.

- www.communities.gov.uk/.../planningandbuilding/pdf/2077834.pdf

While requirements on ventilation are presented in Part F, those relating to airtightness are contained in Part L. Thus airtightness issues are firmly seen in terms of energy impact. However the level of airtightness also has an impact on the sizing of natural ventilation openings and therefore there is cross-reference to Part F.

Specification of Airtightness

In the Building Regulations, airtightness performance is specified in terms of 'air permeability'. This is defined as an airflow rate, in m^3/h, for each m^2 of envelope area at a reference pressure of 50 Pa ($m^3/(h.m^2)$ at 50 Pa). In this case the envelope area is based on the internal dimensions of the building, including the floor area. Verification is undertaken by pressure testing.

AIRTIGHTNESS, ENERGY AND VENTILATION

Mechanical Ventilation Heat Recovery

The fundamental philosophy for airtightness in the UK regulations is to improve energy efficiency and reduce carbon emissions from buildings. In particular, by making buildings air tight, it is believed that there is considerable potential for the implementation of mechanical ventilation heat recovery (MVHR) systems, especially in dwellings. As a consequence, the implementation and quality of airtightness has become inextricably linked to factors such as MVHR performance, energy efficiency, indoor air quality and component durability. The UK Code for Sustainable Homes [5] has placed considerable reliance on airtightness combined with MVHR. These systems are virtually mandatory in the highest specification homes which particularly apply to low income housing association dwellings.

A very recent report of the Zero Carbon Trust concludes that [6]:

- Properly specified, in airtight homes, the provision of MVHR can be beneficial in terms of the energy assessment because the ventilation heat loss is assumed to be minimised. For this reason, as the industry moves towards the zero carbon homes target, it is would appear highly likely that MVHR will become the dominant ventilation system in the majority of new homes.
- Performance evidence from a few studies points to the fact that, working correctly, MVHR is able to have a positive effect on IAQ and health, but clearly this can only be expected to be realised in practice if the system is functioning correctly.

However, the report also presents many problems that affect current performance. These include:

- Examples of failures in typical design, installation and commissioning practice are all too common - badly performing systems may not deliver the anticipated carbon savings and may result in degraded IAQ with related consequences for health.
- Good practice in the design and provision of controls is uncommon
- Concern at the lack of monitoring data that exists for MVHR systems. This, the report states, is a serious issue, given the expectation that these systems are expected to become the dominant form of ventilation, for new homes.

Similar problems are noted in a National House Building Council (NHBC) report [7] which in addition to reporting maintenance issues, notes that “those households with MVHR systems appear to open windows just as much, if not more, than those in homes without the systems, although doing so should generally be avoided”.

Thus there is still considerable progress to be made if airtightness, combined with MVHR, is to become an effective low carbon measure in the UK.

Incorporation of airtightness into the EPBD and Building Regulations

In complying with the Building Regulations, the task of the designer is to achieve an overall energy performance of which air infiltration loss is just one component. The calculation of design energy performance is based on the National Calculation Method (or alternative approved procedure) and forms part of the UK commitment to the EU Energy Performance of Buildings Directive (EPBD). In the case of dwellings the approved calculation method is the "Standard Assessment Procedure" SAP Model) [8] and, for other buildings, it is the Standard Building Energy Model SBEM [9]. The actual level of air tightness that a building needs to attain thus depends on the other components within the calculation method (in particular thermal insulation). Within the Regulations various levels of airtightness are defined; these are:

- The limiting air permeability. In most instances air permeability must not exceed:
  - For dwellings and non-residential: $m^3/(h.m^2)$ at 50 Pa (2010 Regulations)
  - For non-dwellings currently 10 $m^3/(h.m^2)$ at 50 Pa.

For very small developments (1 or 2 houses) or for small residential buildings of floor area less than 500 m^2 the builder can forgo testing and assume a permeability of 15 $m^3/(h.m^2)$ at 50 Pa. The builder must, however, comply with energy performance requirements and hence improve other factors such as thermal insulation accordingly.

- The design air permeability: This may be less than the limiting value and is the value that the designer must achieve in order to fulfil the overall energy efficiency performance of the building design.

- The assessed air permeability: This is either based on the measured value or on the average test result obtained from other dwellings of the same dwelling type on the development increased by a margin of +2.0 $m^3/(h.m^2)$ at 50 Pa. Thus where the assessed air permeability is taken as the average of other test results plus the safety the design air permeability should be at most 8.0 $m^3/(h.m^2)$ at 50 Pa. The assessed air permeability should be at or less than the design air permeability and never exceed the limiting air permeability. In the case of non-residential buildings this is the value used in establishing the Building CO_2 Emission rate (BER).

AIR TIGHTNESS (PRESSURE) TESTING

Testing for Most Types of Dwellings and Non-Residential Buildings

Air tightness testing must be undertaken by an appropriately trained and registered person. This is covered in more detail in the related paper on quality management processes [10]. The test itself must follow the requirements as set out by the Air Tightness Testing and Measurement Association (ATTMA) and the equipment must be calibrated by a United Kingdom Accreditation Service (UKAS) accredited facility. Full requirements for testing can be downloaded from [11] (dwellings) and [12] (non dwellings).

Testing may be undertaken on a sample of buildings. In a large housing development the test should be made on at least three units of each dwelling type. Testing should be undertaken within the construction of the first 25% of each dwelling type so that any faults in design can be corrected before the remaining buildings are constructed.

Testing for Very Large Complex Buildings

In the case of very large and complex buildings it may be impractical to carry out a whole building pressure test. In such circumstances a way of showing compliance is to appoint a competent person to undertake a detailed programme of design development, component testing and site supervision. An absolute best limit for this approach is set at 5 $m^3/(h.m^2)$ at 50 Pa.

Compliance with Airtightness Regulations

Compliance requires that:

- The measured air permeability is not worse than 10 $m^3/(h.m^2)$ at 50 Pa and
- The calculated Dwelling CO_2 Emission Rate (DER) using the measured air permeability is not worse than the Target CO_2 Emission Rate (TER) (dwellings)
- The Building CO_2 Emission Rate (BER), calculated using the measured air permeability, is no worse than the TER (non-dwellings).

AIR LEAKAGE TESTING OF DUCTWORK

Pressure testing of ductwork is required as set out in HVCA DW/143 [13]. Allowable leakage depends on the design static pressure and the maximum velocity. The air leakage limit is expressed in terms of $L/(s.m^2)$ of duct surface area. The actual values are given in [3]. Testing should be carried out for design flow rates of greater than 1 m^3/s.

FUTURE REVISIONS TO THE BUILDING REGULATIONS REGULATIONS

In aiming towards zero and near zero carbon buildings the future Building Regulations are demanding increased energy performance [4]. Proposals are very much preparation documents however they imply some further expectation for tighter buildings. The following permeability values are given in the most recent documents:

- Dwellings: SAP rated notional dwelling [8] 5 $m^3/(h.m^2)$ at 50 Pa
- Non-residential buildings with cooling: 3 $m^3/(h.m^2)$ at 50 Pa
- Non-residential buildings without cooling 5 $m^3/(h.m^2)$ at 50 Pa

THE SITUATION IN SCOTLAND

Scotland has a devolved framework for Building Regulations [14] and the Scottish Government has established a review of requirements for low carbon buildings (Sullivan 2007) [15]. This concluded that:

- Airtightness for building fabric should be improved in 2010 to match those of Nordic countries, but consideration must be given to the social and financial impact of measures that would necessitate mechanical ventilation with heat recovery in domestic buildings.

- The main issue associated with 'PassivHaus' is that to realise the enhanced energy performance and to avoid mould growth arising from condensation, the occupants must be prepared to adjust their lifestyle to rely solely on mechanical ventilation with heat recovery (MVHR), including frequent changes of filters and the associated running costs. The report also explains that this [high airtightness] approach has mainly been used where there has been significant subsidy for those who elected to build and occupy such houses. Also, most importantly, these people had made the decision themselves and had not been forced to live this way through regulation. As such a 'measured' approach is proposed to improving the air permeability of housing, which considers the impact on householders of MVHR.

In developing discussion on airtightness the report has defined possible air permeability levels for future airtightness as:

- Intermediate level: 5 $m^3/(h.m^2)$ at 50 Pa
- Advanced level: 1 $m^3/(h.m^2)$ at 50 Pa

Currently requirements, energy analysis and implementation are similar to the rest of the United Kingdom.

CONVERTING AIR PERMEABILITY TO AIR CHANGE RATE AT 50 PA

For international comparisons the air change rate at 50 Pa is still often used (ac/h50). The comparison of permeability at 50 Pa with air change rate at 50 Pa depends on the ratio of surface area to volume. Thus:

ac/h50 = (air permeability at 50 Pa) * surface area/ volume

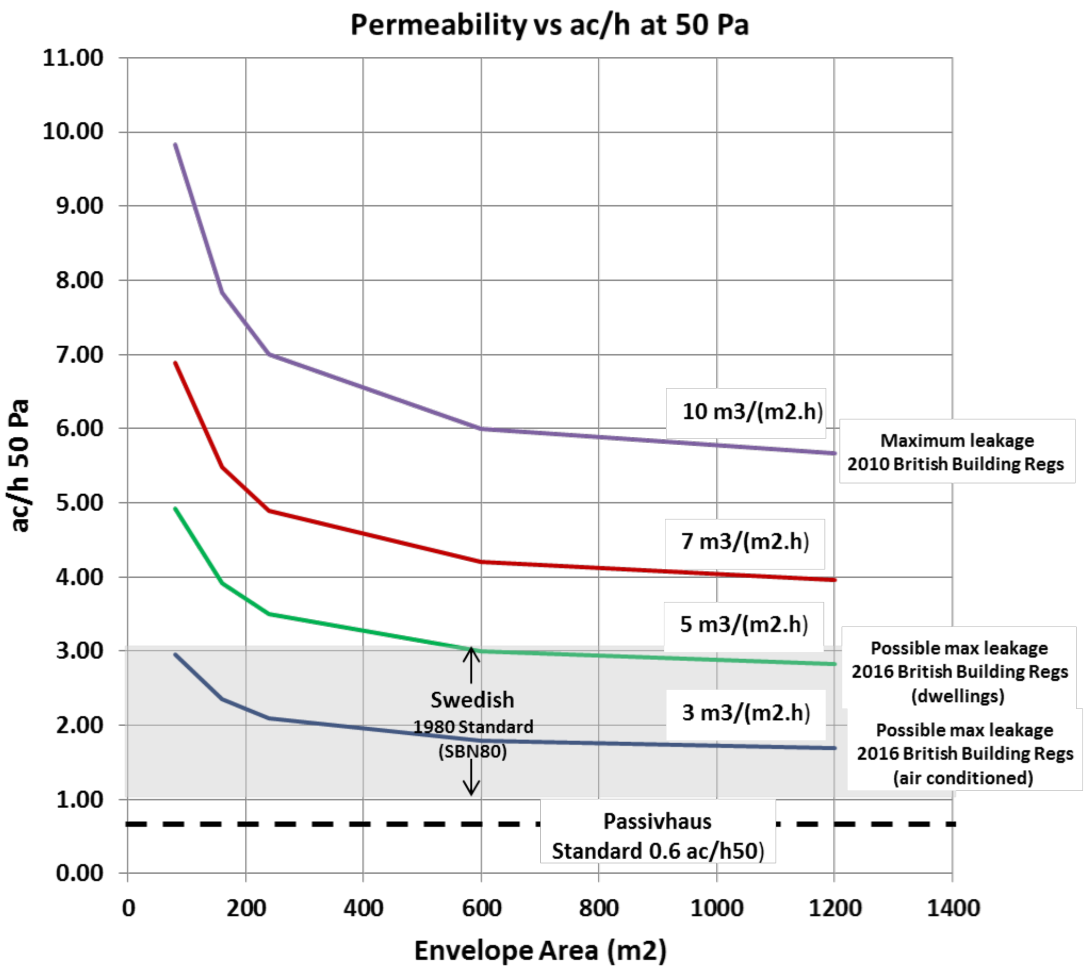

Figure 1. Relationship between Permeability and ac/h at 50 Pa.

For small buildings the surface area can be approximately numerically equivalent to the building volume thus there is a direct equivalence between air permeability and ac/h50. This rapidly falls, however, as the volume of the space increases. This is illustrated for a specific example in Figure 1.

Actual figures and relationships will wholly depend on building shape and size hence the figure presented does not represent a universal condition. For comparison purposes the Figure also includes the ac/h 50 range given in the 1980 Swedish Building Code (SBN 80) [16] and the requirements of Passivhaus. In this context it can be seen that the UK current airtightness limits, especially for small dwelling types, falls far short of the SBN80 requirements of the Swedish 1980 regulations as well as the Passivhaus Standard. Only the airtightness value for air conditioned spaces, as is being proposed for the 2016 Building regulations begins to match the 1980 Swedish regulation.

DURABILITY OF AIRTIGHTNESS

Currently much of the airtightness effort has focused on testing and compliance at the time of construction. Durability results are limited but recent some results are available and are discussed in the associated paper 'UK experience with quality approaches for airtight constructions'[10].

CONCLUSIONS

As the thermal properties of the building fabric improves, air infiltration and uncontrolled ventilation takes an ever increasing proportion of the total building heat loss. As such airtightness and controlled ventilation have become important issues in the quest to move towards zero carbon buildings. To meet this challenge the UK has evolved airtightness requirements which are backed up by a rigourous testing and certification regime.

Airtightness philosophy in the UK is motivated by the need to minimise infiltration losses and maximise the benefit of mechanical ventilation heat recovery systems. The code for sustainable homes places substantial emphasis on MVHR systems.

Airtightness is measured in terms of the air permeability of the building envelope at 50 Pa. In most instances the maximum allowable permeability is 10 $m^3/(h.m^2)$ at 50 Pa. In practice, however, a lower value is usually needed in order to satisfy energy conservation or carbon emission needs. Non testing allowances are made for very small housing developments and commercial premises up to 500 m^3. The developer, however must still demonstrate that energy performance targets will be met for the building. There are also alternative compliance means for very large and complex buildings. Tighter requirements are under consultation for future (2016) Building Regulations.

A Summary Table for reliable testing and reporting is presented at the end of this report.

REFERENCES

[1] UK Government. 2010. *Building Regulations Approved Documents Part F: Ventilation* http://www.planningportal.gov.uk/buildingregulations/approveddocuments/partf/approved

[2] UK Government. 2010. *Building Regulations Approved Document Part L1A: Conservation of Fuel and Power (New Dwellings).* http://www.planningportal.gov.uk/buildingregulations/approveddocuments/partl/approved

[3] UK Government. 2010. *Building Regulations Approved Document Part L1B: Conservation of Fuel and Power (New Buildings other than Dwellings*) http://www.planningportal.gov.uk/buildingregulations/approveddocuments/partl/approved
[4] UK Government. 2012. Consultation on changes to the Building Regulations www.communities.gov.uk/.../planningandbuilding/pdf/2077834.pdf
[5] UK Government. 2010. *Code for sustainable homes technical guide* www.planningportal.gov.uk/uploads/**code**_for_sust_**homes**.pdf
[6] Zero Carbon Hub. 2012. *Mechanical Ventilation with Heat Recovery in New Homes.* Interim Report January 2012 http://www.zerocarbonhub.org/resourcefiles/ViaqReport_web.pdf
[7] NHBC. 2012. *Today's attitudes to low and zero carbon homes Views of occupiers, house builders and housing associations*. NHBC Foundation. Download from: http://www.nhbcfoundation.org/LinkClick.aspx?fileticket=kYluKobXI7A%3d&tabid=496&mid=1170
[8] UK Government. 2011. *The (UK) Government Standard Assessment Procedure (SAP) 2012 Edition (Draft)* http://www.bre.co.uk/filelibrary/SAP/2012/Draft_SAP_2012_December_2011.pdf
[9] UK Government. 2012. *SBEM Simplified Building Energy Model* http://www.bre.co.uk/page.jsp?id=706.
[10] Liddament M. 2012. *UK experience with quality approaches for airtight constructions.* Workshop Tightvent Europe, March 27th – 28th 2012.
[11] ATTMA. 2010. *Measuring air permeability of building envelopes (dwellings)*. Technical Standard L1. http://www.attma.org/downloads/ATTMA%20TSL1%20Issue%201.pdf
[12] ATTMA. 2010. *Measuring air permeability of building envelopes (non-dwellings)* Technical Standard L2. http://www.attma.org/downloads/ATTMA%20TSL2%20Issue%201.pdf
[13] HVCA. 2000. *A practical guide to ductwork leakage testing*. Heating and Ventilating Contractors' Association.
[14] Scottish Government. 2010. *The Scotland Act 2003 Technical Handbook 1 Domestic Buildings (2010 Edition); Technical handbook 2 Non-Domestic Buildings (2010 Edition).*
[15] Sullivan L. 2007. *A Low Carbon Building Standards Strategy for Scotland*, Report of a panel appointed by Scottish Ministers Chaired by Lynne Sullivan 2007, Scottish Building Standards Agency. This document is available on the SBSA website: www.sbsa.gov.uk.
[16] SBN 80 (1980) *Svensk Byggnorm med Kommentarer Chapter 33 Thermal Insulation and Airtightness*. Statens Planverk, Sweden.

SUMMARY TABLE FOR RELIABLE TESTING AND REPORTING

Questions	Answer
Is there a quality framework for airtightness testers in your country?	*All companies and testers must be registered by British Institute of Non-destructive Testing in respect of pressure testing for the air tightness of buildings.* http://www.bindt.org/Air_Tightness_Testing_&_Measurement/Air_Tightness_Testing_Requirements.html *Accreditation is for ATTMA registered companies and for individuals.*
If yes, - what were the reasons behind the development of these frameworks? - what is (are) the body(ies) that issue the certification or qualification?	*British Building Regulations Part L requires testing of the majority of buildings for airtightness using qualified testers.* *Measurements must be undertaken by qualified testers and follow the procedure set out in the ATTMA Guide*
Are there specific guidelines for performing or reporting the airtightness test beyond the requirements of EN 13829 or ISO 9972?	*Measurement methods and reporting is prescribed by the ATTMA*
Are there specific guidelines for the airtightness equipment and software beyond the EN or ISO standards requirements?	*Airtightness testing equipment must be calibrated according to the requirements of the UK Accreditation Service (UKAS) and be used in accordance with the requirements of ATTMA. Software must be based on the National Calculation Methods or alternative approved software.*
What are the steps for a tester to be qualified/certified?	*Attendance at a training approved by ATTMA*
How many testers are qualified according to this framework?	*Several hundred*
Is/are there a specific scheme(s) for airtightness test reporting? If yes, - What were the reasons behind the development of these schemes? - Does it include specific measures to guarantee the accuracy of the airtightness inputs in the EP calculation? - Does it include the collection of test reports by a central body? - Is there a monitoring scheme?	*Reporting procedure is described in Chapter 4 of ATTMA (2010) Measuring Air Permeability in the air envelopes of dwellings. Airtightness testing and measurement association* *To verify and monitor the improvement of building airtightness at national level, etc.* *Results are used directly into calculations to satisfy the building inspector that the required energy performance will be attained.* *Measurement data are retained by the local authority.*
List information and references (preferably in English) on this subject in your country	*[1], [2], [3], [11], [12], [13]*

Table 1. Summary of concerns and lessons learnt regarding reliable airtightness testing and reporting in the UK.

Philosophy and approaches for airtightness requirements in the USA

Max H. Sherman[1] Iain S. Walker[1]

1 Lawrence Berkeley National Laboratory
1 Cyclotron Rd; MS 90-3074
Berkeley, CA 94720, USA
Contact: MHSherman@lbl.gov

ABSTRACT
Building codes and regulations are not normally done at a national level in the United States. Many states and territories have established their own codes and regulations. In addition, there are thousands of local jurisdictions and authorities that set building and hence airtightness requirements. Because of that, there are many non-governmental organizations that help states, counties, utilities and other institutions in setting airtightness methods, requirements and guidelines. This paper will provide some background of Blower Door testing and an overview of the airtightness situation in the US with respect to standards, requirements and approaches.

KEYWORDS
Airtightness, United States of America, codes, standards, requirements, blower-door

INTRODUCTION
In the United States (U.S.) the vast majority of houses, and other low-rise buildings whose ventilation is dominated by envelope air flows, are leaky. That leakage typically supplies most of the ventilation and consumes at least 1/3 of the energy required to keep them conditioned for human occupancy. The ongoing challenge with airtightness is balancing the need to make buildings tighter to save energy and for improved comfort, with the need to provide sufficient air flow to maintain indoor air quality and avoid other issues such as natural draft combustion appliance backdrafting. Where this balance is to be struck is an ongoing topic of debate in the US. The discussion in this paper focuses on residential buildings, primarily because that is currently the focus of air tightness requirements and testing in the US. Larger high rise or industrial buildings generally do not consider envelope airtightness in energy or indoor air quality (IAQ) evaluations because measurements are difficult and it is assumed that mechanical ventilation dominates. However, this is changing, with renewed efforts into measuring the leakage of larger buildings and there are several current research projects examining tightness levels of the current high rise building stock and developing improved measurement and analysis techniques primarily through research sponsored by the American Society of Heating Refrigerating and Air-conditioning Engineers (ASHRAE).

Improving airtightness has been an important part of achieving energy efficiency in the U.S. for over 30 years. There has been a steady improvement of airtightness over that time both in the existing stock, but most clearly in new construction. New homes are typically three times tighter than the existing stock and are sufficiently tight that new homes need designed ventilation systems in order to meet acceptable indoor air quality requirements. In new homes airtighness can be designed-in and energy efficient homes are at about 1 Air Change per Hour at a typical test pressure of 50 Pa (ACH50[h^{-1}]) compared with about 3-5 ACH50 for typical new construction. At these tightness levels some sort of mechanical ventilation is required to provide acceptable indoor air quality. In contrast, existing homes are much leakier – often as much as 15 to 20 ACH50, or greater. Typical attempts to reduce air leakage achieve reductions of about 20% (see for example ref. [19]). Getting beyond that level can be done but the costs to do so can become prohibitive.

The development of the fan pressurization diagnostic (i.e., the "Blower Door" test) has enabled the quantification of air leakage and, therefore, enforceable airtightness requirements. The U.S. has been active for more than 20 years at using this technique to identify and mitigate leaks in existing homes in a variety of programs and identify airtightness limits for natural draft combustion appliances. Standards [1] [2] allow house depressurization by exhaust fans in the range of 2-5 Pa, depending on the appliance, that effectively limit airtightness for homes with unvented combustion appliances inside the conditioned space. These standards are currently under revision that would allow the use of blower door test results in estimating the depressurization in some circumstances rather than measuring it directly. The U.S. has not been as proactive at setting mandatory limits on airtightness.

This paper will review the philosophy of airtightness measurement and limitations as well as approaches used the U.S.

MEASURING AIRTIGHTNESS – BLOWER DOOR TESTING

Blower Doors are used to find and fix leaks in weatherization programs, demonstrate compliance with energy efficiency program requirements (either as tightness levels for new construction or changes in airtightness for existing homes), show that a home exceeds airtightness limits required for natural draft combustion appliances, and, increasingly, the values generated by the measurements are used to estimate infiltration for both indoor air quality and energy consumption estimates. These estimates in turn are used for comparison to standards or to provide program or policy decisions.

Blower doors are used for several purposes in the U.S.:

1. The most common application is in weatherization programs where contractors need to show that air leakage is reduced in order to meet program requirements. In this application the blower door is also used in the process of finding and fixing leaks.
2. To show that a house complies with air leakage limits of voluntary energy efficiency programs, such as the U.S. Environmental Protection Agency (EPA) Energy Star program (www.energystar.gov) or Passive House (www.passivehouse.us) standards.
3. To show that a house complies with building codes such as the credit available in California State building code [3] for tighter envelopes or forthcoming tightness limits in the International Energy Conservation Code [4].
4. To show that a house is leaky enough to avoid depressurization limits for natural draft combustion appliances.
5. To show that a house is leaky enough to not require mechanical ventilation. This is often the case in weatherization programs where limited funds mean that adding a whole house mechanical ventilation system is prohibitively. Typical target leakage is about 12/13 ACH50 (2000 L/s at 50 Pa for a typical home).
6. To determine air leakage for use in energy use calculations. This is commonly the case for homes using voluntary rating systems such as The National Association of Home Energy Raters [5].

This range of applications requires different approaches to air leakage testing. Compliance with standards, for example, requires that the measurement protocols be clear and easily reproducible, even if this reduces accuracy. Conversely, public policy analyses are more concerned with getting accurate aggregate answers than reproducible individual results.

"Blower Door" is the popular name for a device that is capable of pressurizing or depressurizing a building and measuring the resultant air flow and pressure. The name comes from the fact that in the common utilization of the technology there is a fan (i.e. blower) mounted in a door; the generic term is "Fan Pressurization". Blower-Door technology was first used in Sweden around 1977 as a window-mounted fan [6] and to test the tightness of building envelopes [7]. That same technology was pursued at Princeton University (in the form of a Blower *Door*) to help find and fix the leaks [8].

Early on in its development in the US, blower door test results were used as input to models to estimate air flow rates. In its early days a rule of thumb was developed that simply related Blower-Door data to seasonal air change rate: Namely that a representative air change rate can be estimated from the flow required to pressurize the building to 50 Pa divided by 20. More sophisticated models were developed based on physical principles to related airtightness to air flow rates using weather as the driving force. The LBL Infiltration model [9] is based on using blower door results to calculate a leakage area for the home and assuming a pressure exponent of 0.5 in the pressure-flow relationship. An enhanced model [10] has been developed using the measured pressure exponent and leakage coefficient as well as a few other advances such as separating out stacks from other building leakage components. Both of these models can be found in the ASHRAE Handbook of Fundamentals [11]. The LBNL model is used as the basis of energy impacts of ventilation in RESNET home energy ratings. The enhanced model is used in the Canadian HOT2000 software used in the R-2000 program [12].

In the US the idea of using blower door test results in energy calculations was developed in ASHRAE Standard 119 Air Leakage Performance for Detached Single-Family Residential Buildings [13] that set limits on allowable airtightness depending on climate. ASHRAE Standard 136 A Method of Test of Determining Air Change Rates in Detached Dwellings [14] was also developed to relate measured air leakage to annual average ventilation rate suitable for use in IAQ calculations by using weather factors that vary depending on climate. The calculations from Standard 136 had been primarily used in weatherization programs to find a Building Tightness Limit (BTL)[1] and more recently used in ASHRAE Standard 62.2 *Ventilation and Acceptable Indoor Air Quality in Low-Rise Residential Buildings* [15] for determining the ventilation credit to be given to homes that can be used to reduce the mechanical ventilation requirements.

There are two popular procedures for using blower doors. The first is to measure air flow and envelope pressures at multiple pressure stations and this method is standardized in ASTM Standard E779 Standard Test Method for Determining Air Leakage Rate by Fan Pressurization [16]. This multi-point testing allows for the calculation of both C and n in the power law leakage equation:

$$Q = C \cdot \Delta P^n$$

where C is the leakage coefficient (or flow coefficient) and n the pressure exponent. The exponent is typically near 2/3 but theoretically can be anywhere from ½ to 1. Some

[1] As explained in a later section, standard 62.2 is being used in place of the Building Tightness Limit, which is no longer being recommended as an approach for finding optimal airtightness.

applications use these coefficients directly (specifically the enhanced model discussed above) but others used derived quantities such as leakage area at 4 Pa or 10 Pa reference pressures. The LBNL model uses the 4 Pa leakage area defined in ASTM E779. These lower pressures are used for leakage area calculations because they are closer to typical envelope pressures than the test pressures used in the ASTM standard (10-60 Pa). ELA4 is calculated by equating the power law equation to an orifice flow equation at the reference pressure:

$$ELA4 = C\sqrt{\frac{\rho}{2}}(4)^{n-0.5}$$

or by extrapolating from Q50 and converting to orifice flow:

$$ELA4 = Q50\left(\frac{4}{50}\right)^{0.65}\sqrt{\frac{\rho}{8}}$$

where ρ is the density of air.

The second procedure measures the air flow at a fixed pressure of 50 Pa (one of the test procedures in ASTM E1827 [17]). This is referred to as Q50 or CFM50 if the air flow is measured in CFM – which is almost universal in the US. 50 Pa was chosen because it is a high enough pressure that the results are not very sensitive to fluctuations in test conditions (due to wind) – resulting in more repeatable test results, but not too high as to distort the building envelope and open (or close) leaks in the envelope. It also results in air flows that can be produced and measured by typical blower door equipment. Lastly, the fixed pressure approach allows rapid evaluation of tightness measures as they are carried out – a key issue when tightening to a limit. If a leakage area is to be calculated from single point measurements an exponent is assumed – usually 0.65 or 2/3. These typical pressure exponents are based on the analysis of large datasets [18]. This extrapolation using a fixed exponent introduces additional errors when the exponent is different from the assumed value. An estimate of this error can be made knowing that the standard deviation of n is around 0.08 [19]. There is a debate in the U.S. over whether the uncertainties caused by the noise associated with low pressure measurements is greater or less than the bias caused by not knowing the exponent. The authors are currently preparing an analysis of this issue.

A notable exception to the 50 Pa measurement pressure is for duct leakage, where duct pressurization tests are performed at 25 Pa. This fixed pressure testing of ducts is almost universal with the exception of the DeltaQ test that tests ducts over a range of pressures. Both approaches are covered by ASTM E1554 Determining Air Leakage of Air Distribution Systems by Fan Pressurization [20]. The pressurization test procedure is also included found in many other documented locations such as RESNET Standards, BPI standards, weatherization programs, energy efficiency programs for national, state, utility and labeling schemes.

Norms and normalization

The metrics above all refer to the total amount of leakage of the tested envelope. For setting norms or standards, or for comparing one structure to another it is often desirable to normalize this total by something that scales with the size of building. In that way buildings of different sizes can be evaluated to the same norm.

There are three quantities commonly used to normalize the air leakage: building volume, envelope area, and floor area. Each has advantages and disadvantages and each is useful for evaluating different issues:

Building volume is particularly useful when normalizing air flows. When building volume is used to normalize such data the result is normally expressed in air changes per hour at the reference pressure. 50 Pa is often used as the reference pressure because this pressure is commonly used for air flow measurements. This is referred to as ACH50 (or *n50* in Europe). Many people find this metric convenient since infiltration and ventilation rates are often quoted in air changes per hour and ACH can be used to estimate changes in relative concentration of pollutants in IAQ analyses. Rules of thumb are often applied to convert ACH50 to air flow under natural conditions, e.g., dividing ACH50 by 13 to get a natural air change rate.

$$n50 = ACH50 = Q_{50} / DwellingVolume$$

Being based on Q50, this quantity has the same accuracy limitations. In addition, there is a practical limitation that the volume of a dwelling may be time consuming to measure. In addition, programs using this metric do not all agree on the methods for determining building volume.

Envelope area is particularly useful if one is looking to define the construction quality of the envelope. Dividing a leakage parameter (particularly leakage area) by the envelope area makes the normalized quantity a kind of porosity. Although this normalization can sometimes be the hardest to use due to difficulty in determining envelope area for all but very simple structures, it can be particularly useful in attached buildings were some walls are exposed to the outdoors and some are not.

Floor area can often be the easiest to determine from a practical standpoint because all homes need it for real estate documentation and occupants often know it. Because usable living space scales most closely to floor area, this normalization is sometimes viewed as being more equitable. Specific Leakage Area (SLA) is used in both RESNET and California Building Standards and is defined as the ratio of ELA to Floor area. In the California standard, this ratio is multiplied by a factor of 10,000 for convenience to create values roughly in the range of 1 to 10.

$$SLA = \frac{ELA}{FloorArea}$$

ASHRAE Standard 119 has created a dimensionless metric, called Normalized Leakage (NL), which is both based on ELA and normalized by floor area:

$$NL = 1000 \cdot \frac{ELA}{FloorArea}\left(NumberOfStories\right)^{0.3}$$

where the number of stories terms helps correct for the fact that buildings that are taller will have more infiltration for a given amount of leakage. The factor of 1000 is a scaling term that makes the normalized leakage be approximately the same magnitude as the natural air changes per hour. Normalized leakage more accurately describes the relative amount of infiltration when comparing two dwellings in the same climate.

APPLICATIONS OF AIRTIGHTNESS TESTING

The applications of airtightness testing depend on the purpose for testing. The US differentiates between "codes" and "standards". A "code" is a regulation that has the force of law in a particular jurisdiction. Most building codes are issued and enforced at the local level and there are a few thousand such jurisdictions in the U.S. A "standard" is not regulatory, however, many codes refer to standards. For example, ASHRAE Standard 62.2 is a standard for achieving acceptable indoor air quality. But it is not a regulation. Building codes refer to ASHRAE 62.2 in legislation by requiring compliance with the standard.

Because there are so many code bodies, there exists "model codes" which are created by an independent body and are used either completely or as a basis for the local codes. The relevant model code for energy in buildings is the International Energy Conservation Code (IECC) promulgated by the International Code Council (ICC) whose adoption varies by state [21]. The latest (2012) version of the IECC has introduced maximum air leakage levels for residential buildings that depend on climate, as defined by DOE Climate zones. The requirements are 5 ACH50 for mild climates (Climate zones 1 and 2) and 3 ACH50 elsewhere. It also requires a prescriptive checklist of airtightness measures, such as the use of air barriers and sealants. There are no training requirements, meaning that anyone can perform the testing. There are also no third party requirements for testing or verification – thus allowing builders to self-certify.

There are jurisdictions that do not use the IECC codes and have their own energy code. The State of California (which is approximately 10% of the U.S. housing stock), for example has its own state energy code. The California code uses specific leakage areas calculated from Q50, that can be derived from single or multi-point blower door tests, to be used in compliance software that uses it to calculate hour by hour ventilation rates. There is no requirement to test for air leakage. If no test is done, a default SLA is set in the standard of 4.3 (this includes a multiplier of 10,000 as noted above). This is lowered to 3.8 for a home with sealed ducts (verified by duct testing) and 3.2 for a home with no duct system. There is also a credit of an SLA reduction of 0.5 for a home with an air retarder that requires no testing. Credit can be taken for air leakage below these limits. There is a restriction for homes with an SLA below 1.5 requiring balanced mechanical ventilation. Finally, there is a requirement that homes comply with ASHRAE Standard 62.2.

In addition to these whole house airtightness limits, codes regulate other aspects of air leakage. A key example is for homes with attached garages where the house-garage interface is required to be substantially air tight and gasketed doors are required. ASHRAE Standard 62.2 has similar requirements and additionally requires that any ducts in the garage meet a tightness limit of 6% of total fan flow at 25 Pa. Other code requirements for windows and insulation have indirect impacts on air leakage.

RESNET has a standard method for rating homes that includes air leakage testing. By referring to ASHRAE Standard 119, that in turn, refers to ASTM E779, this requires multipoint testing. The metric used is SLA[2] with a default of 0.00048. A house tighter than this will get a better rating and a looser house a lower rating. RESNET is currently working on new standards for home diagnostics that include air leakage testing and will have a single-point test procedure as well as multipoint.

[2] Note: RESNET's definition of SLA does not include the factor of 10,000. There is no standard for SLA.

The Building Performance Institute (BPI) writes standards used for training and certifying contractors and refers to ASTM E779 directly as the method for assessing envelope leakage. As with RESNET, new BPI standards are currently being written that incorporate single point testing.

Standards do not have any regulatory authority, but they do represent the best knowledge of the relevant technical or professional body about the subject at hand. ANSI is the body that certifies American National Standards. ANSI standards related to airtightness measurements have been published by ASHRAE and ASTM, and BPI is seeking ANSI certification for its new standards.

The largest Federal program that involves air tightening is the Weatherization Assistance Program (WAP). This program subsidizes energy efficiency retrofits for low-income Americans and sets standards for doing so. WAP programs follow standard work specifications which are currently out for public comment. The new version of the specifications would facilitate improved air tightening by allowing funds to be used for ventilation which meets ASHRAE Standard 62.2. Until recently many weatherization practitioners used what is known as a Building Tightness Limit, which was a tightness limit that determined when a mechanical ventilation system was necessary. To avoid the expense of installing a mechanical ventilation system in a retrofit situation, it had become common practice to tighten only to this limit and then stop. This approach is not optimal for energy savings, even after the costs of a ventilation system are included. With recent changes to ASHRAE Standard 62.2, the BTL has fallen out of favour and more and more programs are tightening better and then installing mechanical ventilation systems. The State of Wisconsin has been a leader in this area and has tightened thousands of homes and put in mechanical ventilation to meet Standard 62.2.

The US Environmental Protection Agency (EPA) has several voluntary programs that refer to airtightness. For existing homes, both Home Performance with Energy Star and EPA's Home Retrofit Protocols refer to ASHRAE 62.2 for minimum ventilation rates and therefore, by reference to optional air leakage measurement for ventilation credit for leaky homes. For new homes, EnergyStar Version 3 includes airtightness limits in ACH50 based on DOE Climate Zone. In climate zones 1 and 2 the limit is 6 ACH50, for climate zones 3 and 4 it is 5 ACH50, for climate zones 6 and 7 it is 4 ACH and climate zone 8 requires an ACH50 below 3. The ACH50 value is determined using the current RESNET protocol that refers to ASTM E779 multipoint testing. EPA also has an IAQ checklist that is separate from the EnergyStar Version 3 national program requirements and requires compliance with ASHRAE 62.2. The US Green Building Council LEED for Homes Certification has climate specific envelope leakage requirements.

Looking forward: With the publication of the 2013 version of ASHRAE Standard 62.2 (and the existence of IECC 2012), we anticipate that both standards 119 and 136 will be withdrawn by ASHRAE. The critical parts (i.e. of incorporating airtightness in minimum ventilation calculations) are in 62.2 now. Airtightness requirements much more stringent than those in the IECC may not make sense as prescriptive requirements and should be considered in a whole-building context. We also expect that test methods for measuring airtightness will be updated within the next year or two.

SUMMARY

Although historically homes in the US were leaky, there is now more awareness of the necessity of building tight homes while ensuring minimum ventilation rates using mechanical systems, and the industry is adopting the mantra of "*Build Tight – Ventilate Right*". Although there is no national regulation of airtightness, many jurisdictions, regulatory bodies, codes and standards associations are beginning to include requirements for limiting envelope. Because they are driven by energy reduction, these limits often depend on climate. There is currently a range of allowable leakage levels that are not the same depending on which code or standard is being referenced. However, the US is reaching consensus on minimum ventilation rates given by ASHRAE 62.2. Although current airtightness testing of homes is restricted to homes that get energy ratings this is set to increase substantially in the future, primarily due to changes in the IECC.

There are increasing efforts to at least make testing more uniform using blower door techniques. ASTM Standard E779 has been in existence for many years and is often referred to where multipoint testing is required. For single point testing, training and certification programs and rating standards are working to have standardized procedures.

Other efforts to unify airtightness issues are looking at combustion appliance safety testing – that is of particular concern when tightening existing homes.

Production builders in the US regularly build homes with leakage below 5 ACH50. Current construction techniques can get this as low as about 1 ACH50, but achieving lower levels, such as those required for Passive House require considerable extra effort and expertise and are unlikely to become common any time soon. Furthermore the energy benefits of achieving such levels may be minor, while the system robustness decreases. Existing homes show considerable scope for tightening and most retrofit and weatherization programs make considerable efforts to address air leakage. Reductions are limited by access to leak sites making it difficult for existing homes to be tightened to the same level of airtightness as new homes, but reductions of 20% or more are readily achievable.

ACKNOWLEDGEMENTS

Funding was provided by the U.S. Dept. of Energy Building Technologies Program, Office of Energy Efficiency and Renewable Energy under DOE Contract No. DE-AC02-05CH11231.

REFERENCES

[1] CGSB. 2005. *Canadian National Standard CAN/CGSB-51.71-2005 Depressurization Test*. Canadian General Standards Board, Gatineau, Canada.

[2] BPI. 2012. *Building Analyst Professional Standard*, Building Performance Institute, Malta, NY.

[3] CEC. 2008. *Title 24, Part 6, of the California Code of Regulations: California's Energy Efficiency Standards for Residential and Nonresidential Buildings*. California Energy Commission 2008. Available from http://www.energy.ca.gov/title24

[4] ICC. 2012. *2012 ICC International Energy Conservation Code*, International Code Council, Janesville, WI.

[5] RESNET 2006. *2006 Mortgage Industry National Home Energy rating System Standards*, Residential Energy Services Network, Oceanside, CA.

[6] Kronvall J. 1980 *Airtightness Measurements and Measurement Methods,* Report D8, Swedish Council for Building Research, Stockholm, 1980.
[7] Blomsterberg A., 1977. *Air Leakage in Dwellings*, Dept. Bldg. Constr. Report No. 15, Swedish Royal Institute of Technology.
[8] Harrje D.T., Blomsterberg A. and Persily A.K. 1979 *Reduction of Air Infiltration Due to Window and Door Retrofits*, CU/CEES Report 85, Princeton University.
[9] Sherman, M.H., and Grimsrud, D.T. 1980. *The Measurement of Infiltration using Fan Pressurization and Weather Data.* Report # LBL-10852, Lawrence Berkeley Laboratories, University of California.
[10] Walker, I.S. and Wilson, D.J. 1998. *Field Validation of Equations for Stack and Wind Driven Air Infiltration Calculations,* ASHRAE HVAC&R Research Journal, Vol. 4, No. 2, pp. 119-140. April 1998. ASHRAE, Atlanta, GA.
[11] ASHRAE. 2009. *Handbook of Fundamentals*. American Society of Heating, Refrigerating and Air-conditioning Engineers, Atlanta, GA.
[12] Natural Resources Canada. 2005. *R-2000 Standard*, Natural Resources Canada, Ottawa, Canada
[13] ASHRAE. 1988. *ASHRAE Standard 119, Air Leakage Performance for Detached Single-Family Residential Buildings*, American Society of Heating, Refrigerating and Air conditioning Engineers, Atlanta, GA.
[14] ASHRAE. 1993. *ASHRAE Standard 136 A Method of Test of Determining Air Change Rates in Detached Dwellings.* American Society of Heating, Refrigerating and Air conditioning Engineers, Atlanta, GA.
[15] ASHRAE. 2010. *ASHRAE Standard 62.2 Ventilation and Acceptable Indoor Air Quality in Low-Rise Residential Buildings*. American Society of Heating, Refrigerating and Air conditioning Engineers, Atlanta, GA.
[16] ASTM. 2010. *ASTM Standard E779-10. Determining Air Leakage Rate by Fan Pressurization*, American Society for Testing and Materials, West Conshohocken, PA.
[17] ASTM. 2007. *ASTM Standard E1827-96 Standard Test Methods for Determining Airtightness of Buildings using an Orifice Blower Door.* American Society for Testing and Materials, West Conshohocken, PA.
[18] Orme, M., Liddament, M., and Wilson, A.1994. *An Analysis and Data Summary of the AIVC's Numerical Database*, Tech. Note 44, Air Infiltration and Ventilation Center, Coventry, UK.
[19] M.H. Sherman, D. J. Dickerhoff. 1988. *Airtightness of U.S. Dwellings*,"ASHRAE Trans., 104(2), pp. 1359-1367.
[20] ASTM. 2007. *ASTM Standard E1554-07. Standard Test Methods for Determining External Air Leakage of Air Distribution Systems by Fan Pressurization*, American Society for Testing and Materials, West Conshohocken, PA.
[21] http://www.energycodes.gov/states/maps/residentialStatus.stm

PHILOSOPHY AND APPROACHES FOR AIRTIGHTNESS REQUIREMENTS IN DENMARK

Alireza Afshari[1], Niels Christian Bergsøe*[1]

1 Danish Building research Institute, Aalborg University
Dr. Neergaards Vej 15
2970, Hoersholm, Denmark
**Corresponding author: ncb@sbi.dk*

ABSTRACT
Improved energy performance of buildings cannot be achieved only by additional insulation, effective building systems and energy-efficient ventilation systems. Airtightness of building envelopes is also important for the control of energy loss. As a result of the Danish implementation of EU Directive 2002/91/EF on the Energy Performance of Buildings in Danish legislation, stricter energy requirements were introduced in the Danish Building Regulations, including requirements for tightness of building envelopes.

The requirements came into force on 1 January 2006 and continued with few changes in the current Building Regulations (BR10). Airtightness of the building envelope must be determined according to EN 13829 and the specific leakage rate at 50 Pa pressurisation must be less than 1.5 l/s per m^2 heated floor area.

The paper presents an overview of the existing airtightness requirements for improved energy performance of buildings in Denmark. Two experimental studies are presented here. One of the studies deals with the energy performance of residential buildings and the other deals with the experience gained from carrying out airtightness measurements of large building envelops.

KEYWORDS
Airtightness, Building envelops, Energy performance, Building regulations

INTRODUCTION
The function of the building envelope is to protect the indoor climate from the outdoor climate. One of the essential properties for a high-efficiency building envelope is airtightness. The more airtight the envelope, the lower the air infiltration and the easier to ensure total building performance including among others sufficient thermal comfort, indoor air quality and energy.

The requirements in the Danish Building Regulations (BR 10) regarding airtightness and the building envelope are that air change must not exceed 1.5 l/s per m² of the heated floor area when tested at a pressure of 50 Pa. In the case of low energy buildings, air changes through the building envelope must not exceed 1.0 l/s per m². The result of the pressure test must be expressed as the average of measurements using pressurisation and depressurisation. In the case of buildings with high ceilings, in which the surface area of the building envelope divided by the floor area is more than 3, air changes must not exceed 0.5 l/s per m² of the building envelope and in the case of low energy buildings 0.3 l/s per m² [1].

The procedure for measurements of airtightness in Denmark follows the European standard EN 13829. The standard describes a standardised procedure for different airtightness measurements (e.g. method A or B) [2]. According to EN 13829 a building with a volume of more than 4000 m^3 is characterised as a large building.

SBi (the Danish Building Research Institute) has drawn up SBi Guidelines 214. The Guidelines is based on a compilation and communication of existing knowledge and includes the causes of air leakages in the building envelope, a description of measurements of airtightness and examples of good solutions for ensuring airtightness [3].

The Building Envelope Society (KLIMASKARM) is a platform and a society for measurement of airtightness and Infrared thermographic of buildings. In collaboration with DS Certification, the society established certification schemes for measurement of airtightness and Infrared thermographic of buildings [4].

EXPERIENCE GAINED FROM AIRTIGHTNESS MEASUREMENTS

Pressurisation technique according to DS/EN 13829 was used for measuring the airtightness and air leakage of building envelopes. The equipment is capable of pressurising or depressurising a building and measuring the resultant airflow and pressure. These tests determine the air-infiltration rate of a building. Infrared thermographic photography was used together with the fan in order to achieve a visual illustration of the air-leakage locations.

This paper presents the results of two experimental studies in order to describe challenges when working with the airtightness measurements of small and large building envelopes. The buildings were built between 2005 and 2009. One of the studies deals with the energy performance of residential buildings [5] and the other study deals with the experience gained from airtightness measurements of large building envelopes [6].

Residential building

The objective of the studies was to clarify whether the recently built residential buildings comply with the requirement of the airtightness and the air change rates stipulated in the Danish Building Regulation (BR 10).

Study of detached houses built 2005-2011:
Figure 1 shows the results of measurements of the airtightness of 27 detached houses in Stenløse Syd, Egedal municipality. The houses are listed as low-energy housing. Although the houses were designed before the current requirements for building-envelope airtightness existed, there was considerable focus during construction on ensuring tight housing.

Study of detached houses built 2007-2009:
Figures 2 and 3 show the results of two different investigations of the average outdoor supply air and the measurements of the building envelope airtightness of 24 detached houses. The houses were built between 2007 and 2009, except one which was built in 2006. Information on ventilation and heating in the houses was evident from the figures. Houses Nos. 3, 5, 9, 11, 13, 18, 20 and 23 had natural ventilation and the remaining houses had mechanical ventilation with heat recovery.

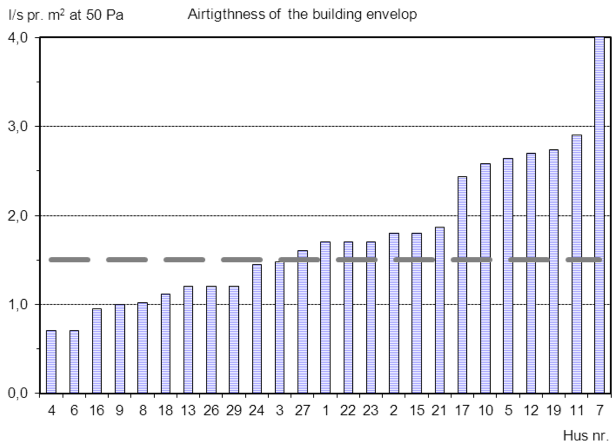

Figure 1. The results of the building envelope airtightness measurements of the 27 detached houses in Stenløse Syd, Egedal municipality. The grey dashed line indicates maximum air changes through leakage in the building envelope at a pressure of 50 Pa according to the Danish Building Regulations (BR 10).

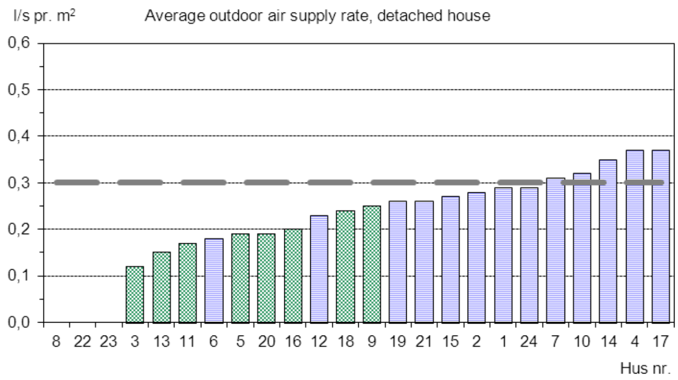

Figure 2. Average outdoor air supply rate. Measuring period 1-2 weeks. The light blue columns are houses with mechanical ventilation with heat recovery, while the green bars are naturally ventilated houses. The grey dashed line indicates the requirements stipulated in the Danish Building Regulations of 0.3 l / s per m^2 gross floor area.

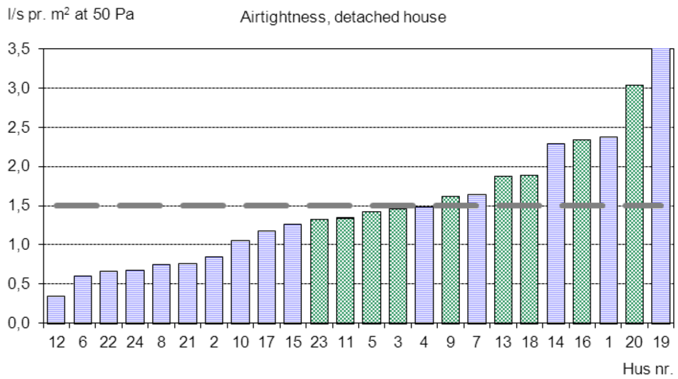

Figure 3. Building envelope airtightness measurements. The light blue columns are houses with mechanical ventilation with heat recovery, while the green bars are naturally ventilated houses. The grey dashed line indicates maximum air changes through leakage in the building envelope at a pressure of 50 Pa according to the Danish Building Regulations (BR 10).

Large buildings

Experience on the airtightness of the building envelope in large buildings is limited. Large buildings are often unique, and it is difficult to generalise and to transfer experience from one building to another. This poses particular challenges to making airtightness measurements in large buildings.

Based on contacts with the involved companies in the project, a unique combination of results has been prepared based on a large number of airtightness measurements in large buildings. The measurements were carried out in 57 buildings, of which 27 were offices, 2 archives, 5 kindergartens, 6 schools and 17 other kinds of buildings. Figure 1 shows the measured air leakage at 50 Pa, w50 [l / s per m^2] of the heated floor area.

The results showed that it was possible to obtain the required airtightness in large buildings, and in most of the buildings achieve results which were better than the required maximum of 1.5 l / s per m2 according to the Danish Building Regulations (BR 10).

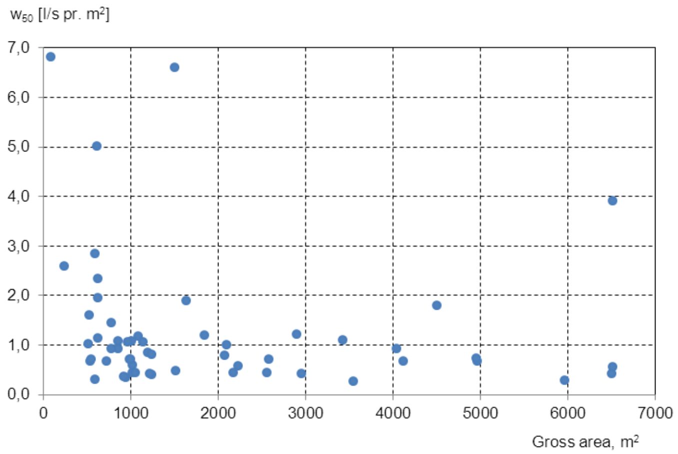

Figure 4. Comparison of the results of the measurements of the airtightness in large buildings.

Discussion

Residential buildings
Study of detached houses built 2005-2011:
The results of the measurements of the building envelope airtightness of 27 detached houses in Stenløse Syd Egedal municipality showed that approx.. 50% of the houses did not comply with the requirements. It should be noted that there is no information on the air change rates in the houses.

Study of detached houses built 2007-2009:
The results of measurements of the building envelope airtightness of the detached houses showed that approx.. 2/3 of the houses (15 of 24 houses) complied with the requirements to airtightness according to the Danish Building Regulations (BR 10). It seems that 9 of the houses did not meet the requirements, see Figure 3. House No. 19 was very leaky. The reason was that in connection with renovation the residents had changed the airtightness of the building. The house was not examined by negative pressure due to the risk of damaging the vapour barrier.

There were 9 naturally ventilated detached houses in the study, 4 of the houses just met the requirements to airtightness, while the other 5 houses did not meet the requirements, of which 2 are respectively 50 % and 100 % above the requirements.

Figure 5 shows the measured average outdoor air supply rate in relation to the measured building envelope airtightness. As shown in Figure 2, there was lack of the measured outdoor air change rates for 3 of the houses including House No. 23, which was naturally ventilated. Therefore, Figure 5 only shows 8 naturally ventilated houses. The figure shows no clear correlation between the measured outdoor air change rates and the measured building envelope airtightness.

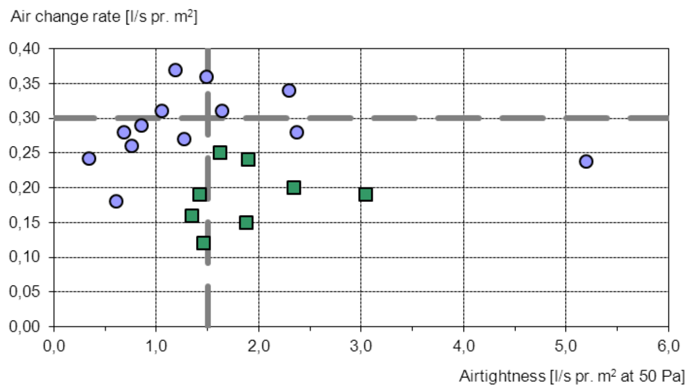

Figure 5. The average outdoor air supply rate versus the building envelope airtightness. The blue circles are houses with mechanical ventilation, while the green squares are naturally ventilated houses. The grey, dotted lines denote the requirements in the Danish Building Regulations for fresh air supply and for the airtightness of building envelope.

Large buildings
Experience gained from measuring the envelope airtightness of the large buildings was that the practical preparations put restriction on the use of the building for a period of perhaps a day or two or a weekend. The preparations included sealing of openings, interruption of certain technical installations, possible closure of parts of the building, etc. The measurement itself precluded access and exit of the building.

There were indications that economic aspects might also influence the extent of measurements in large buildings. It takes time to make a large building ready for an airtightness measurement, and it may be necessary to obtain or borrow additional equipment including fans for the measurement. Nevertheless, if the cost of measurement of airtightness should be related to construction prices, it would appear that for a detached house, the cost of the airtightness measurement is in the order of 0.3 % of the construction cost, while the cost of testing a large building represents about 0.03 % , i.e. a difference of a factor 10.

The interest in determining the airtightness is greatest in the case of detached houses, in which the owner and the user is in most cases the same. However, in large buildings, the owner/developer bears the cost both of achieving a tight building envelope and the measurement of the airtightness of buildings, while it may be a tenant who reaps the benefits in terms of lower energy costs and better indoor climate.

There is a need to disseminate knowledge about the importance of an airtight building envelope. The building owner/developer should understand that the airtightness of the buildings is not only a question of lower energy consumption. They should observe that it is also a question of reduced risk of problems with condensation and moisture in the construction, better indoor air quality, etc.

It presents significant challenges to convince the management of a company to make a building available for airtightness measurements. The reason for this reluctance is not that clear, but may be associated with the need to limit the use of the building during the preparation and during the actual airtightness measurements. Also, it seems as if airtightness measurements in existing large buildings are only carried out if there is a special reason.

In new large buildings, it will be somewhat easier to organise airtightness measurements of the building envelope. It requires that the subject of airtightness is brought into focus at an early stage in the design process. The project plan must include the time and financial plans of the airtightness measurement and thus prepare drawings and solution details. It may be advantageous to appoint a person who is responsible for ensuring that the methods and materials guarantee that the building airtightness will comply with requirements. Another option is to contract with a company specialising in building airtightness. They have experience with such projects and consequently they are able to reduce the number of errors and measurements significantly.

When the airtightness of a building is brought into focus at an early stage of a project, it could be cheaper to carry out the measurements. However, it is surprising that the price of airtightness measurements is significant, as the cost of airtightness measurements in a large building typically represents less than 1 per thousand of the construction costs.

Airtightness measurements showing that the envelope does not comply with requirements may result in high costs for repairing the leaks. Such a situation can be mitigated by conducting the airtightness measurements of a section of the facade at an early stage in the construction phase. The selected facade section must be completed and representative of the building. The test can - and should - be done before the facade is completed. The result of the airtightness measurements and experience with construction and sealing of an approved facade section can be used to construct the remaining part of the facade of the building. This increases the probability that the building as a whole will comply with the requirements at the first test, and therefore it will not be necessary to reserve time and finances for a later tightening of envelope and repair.

CONCLUSION

Residential buildings
Study of detached houses built 2005-2011:
The results of measurements of the building envelope airtightness of 27 detached houses in Stenløse Syd, Egedal municipality showed that approx. 50% of the houses did not meet the requirements to airtightness in the Danish Building Regulations (BR 10). There is no information on the air change rates in the houses.

Study of detached houses built 2007-2009:
The results of measurements of detached houses (15 with mechanical ventilation, 9 with natural ventilation) show that:

- 15 of 24 houses (about 63 %) meet the requirements to airtightness stipulated in the Danish Building Regulation (BR 10)
- 4 of 9 naturally ventilated houses meet the requirements to airtightness stipulated in the Danish Building Regulation (BR 10)
- 2 of the 5 naturally ventilated single family houses that did not meet the requirements to airtightness in the Danish Building Regulation (BR 10), were respectively 50 % and 100 % above the required

Large buildings:

- It appears from the measurements that there are buildings that do not meet the requirements of airtightness in the Danish Building Regulation (BR 10)
- It is uncertain how many buildings that do not meet the requirement at the initial test.
- It presents very significant challenges to convince the management of a company to make a building available for a envelop airtightness measurement.
- Based on experience, it is not possible to carry out airtightness measurements in existing large buildings without a special reason.
- In new, large buildings, it will be somewhat easier to organise airtightness measurements of the building envelope. It requires that the subject is brought into focus at an early stage in the design process.
- It may be convenient to make possible the airtightness of a not yet finished facade based on the tests of a ready-made section of the facade. The advantage is that verification can be made at an early stage in the construction process, making it easier and cheaper to provide airtightness for the remainder of the facade.

ACKNOWLEDGEMENTS

SBi wishes thanks to the all authors and the organisations involved in the two studies for the results presented in the present paper.

REFERENCES

[1] Danish Building Code BR2010 http://www.ebst.dk/file/104440/bygningsreglement.pdf
Older Building Codes http://www.ebst.dk/br08.dk.

[2] European Committee for Standardization. 2000. EN 13829:2000 *Thermal performance of buildings - Determination of air permeability of buildings - Fan pressurization method* (ISO 9972:1996, modified).

[3] Rasmussen, T. V. & Nicolajsen, A. 2007. *Klimaskærmens lufttæthed*. Hørsholm: Statens Byggeforskningsinstitut, SBI. 44 s. (SBi-anvisning; 214).

[4] www.klimaskaerm.dk

[5] Bergsøe, N.C. 2011. BR's boligventilationskrav. Beherskes kravene og efterleves de i nye boliger: Tekniske samtaler. Nye målinger, SBi 2011: 21, Denmark.

[6] Bergsøe, N.C., Radisch, N.H., Nickel, J., Treldal, J., Bundesen, E.W., Nielsen, C. 2011. Klimaskærmens tæthed i kontor- og undervisningsbygninger, SBi 2011:17, Denmark.

PHILOSOPHY AND APPROACHES FOR AIRTIGHTNESS REQUIREMENTS IN FINLAND

Timo Kauppinen[*1], Sauli Paloniitty[2], Juha Vinha[3], Anu Aaltonen[3] and Elina Manelius[3]

1 VTT Technologies and Services for Buildings
Kaitoväylä 1
PO Box 110, FI-90591 Oulu Finland
timo.kauppinen@vtt.fi

2 HAMK University of Applied Sciences
Visamäentie 35 B
PO Box 230, FI13101 Hämeenlinna Finland

3 Tampere University of Technology
Tekniikankatu 12, PO Box. 600
33101 Tampere Finland

ABSTRACT

In this presentation the development of requirements which are in connection with air tightness of buildings has been introduced. In Finland there have been no exact direct requirements for air tightness, but new building codes require energy efficiency calculations, where also air tightness is one factor. In the new building codes also maximum value of q50 is fixed at 4 (m3/h·m2). This default value set q50 for air tightness is used if air tightness is not determined by measurement or by other method. This leads to achieve an appropriate level of air tightness. From the year 2007 on the buildings must have energy efficiency calculations, which requirements are now part of Building Code Book. The latest version will come into force in 2012. This is based on European Performance of Buildings Directive. Also the general tendency to better energy performance and energy efficiency in general has been one factor. A review of some recent and older results of air tightness is represented and conclusions and appraisals of air tightness as a part of energy efficiency of buildings.

KEYWORDS

Air tightness, Performance of Buildings, Energy Efficiency of Buildings, Air Leaks, Air Infiltration

INTRODUCTION

In Finland the first systematic approaches to measure air tightness of buildings were made by VTT in the turn of 70`s and 80`s. Some measurements were done before at 70´s e.g. ordered by City of Helsinki, using the own ventilation system of a building. There were no requirements in building codes dealing with air tightness of buildings, only in very general level. The situation remained more or less the same until late 90`s when some larger scale studies were launched. Most of the studies were focused on apartment houses: one-family and row houses. Air tightness tests combined with thermography became more general during 80´s and 90`s, but mainly because of growing awareness of the building owners and also the improved quality control activities of prefabricated house manufacturers. The main reason for air-tightness tests was reclamations – caused by decreased thermal comfort, cold surface temperatures or draft. These measurements were made both in case of new houses and in connection of sale contracts. VTT preferred always two-stage thermography combined with air-tightness measurements. Air-tightness measurements of multi-story houses were made relatively seldom. Building thermography services were asked more often, for instance in case of the quality of window installations. During 70`s – 90`s there were few commercial thermography services providers and actually no private services for air-tightness measurements. The research service units of some technical colleges had readiness for air tightness measurements. The common knowledge about air tightness-related matters was not so high even among the professionals (in practice) even the significance of air-tight structures and the problems caused by uncontrolled air infiltration was recognized.

Some special facilities had, anyway, requirements for uncontrolled ventilation written in the building documents. A full-size multipurpose/football hall in Eastern Finland which was completed 1992 had demand for air-tightness (the maximum rate of uncontrolled ventilation) and it was measured using tracer gas (nitrous oxide) by concentration decay method.

The 2nd version of Indoor Air Classification 2000 was published 2001 (replaced the first version from the year 1995) and recommendation for air-tightness of buildings was set as follows [1]:

Indoor air classes (S1-S3, S1 = best)			
Air leak number n50 (1/h)	**S1**	**S2**	**S3**
Buildings under three floors	2,0	2,0	3,0
Higher buildings	1,0	1,0	2,0

Table 1. Air tightness recommendations of Indoor Air Classification 2000

In contemporary buildings codes was mentioned that recommended air leak number n50 should be 1, 0 1/h – in the connection of good performance of mechanical ventilation system.

Indoor Air Classification was renewed 2008 (valid from 2009 on), and the new recommendations were written like this [2]: “The building developer must select a goal for air tightness dealing with indoor air quality (classes S1 and S2) and the air barrier solution equal to the selected air tightness level must be shown in the design documents. The goal for air-tightness must be chosen in co-operation with HVAC-designer”. The recommendations for maximum values are presented in table 2. Now also q50 was taken into recommendations.

Indoor air classes (S1-S2)		
Air leak number q50 (m3/h,m2)	**S1-S2**	**n50 (1/h)**
One-family houses	<1…1,5	<1,0…2,0
Other buildings	<0,5…0,7	
Apartments		0,5…0,7*

*(including external and both internal leaks through exterior walls, floors and intermediate walls)

Table 2. Air tightness recommendations of Indoor Air Classification 2008

The selected goal for air-tightness gives a possibility to verify the realized level of air tightness by measurements. Air tightness must be measured according the standard SFS-EN 13829 [3]. This recommendation gives also some detailed instructions how the measurements must be carried out. These recommendations and Indoor Air Classification was created to help the industry, designers and manufacturers when the aim is to build healthier and more comfortable buildings – it can also be applied in renovation to the appropriate extent.

The significance of air-tightness was admitted and during the next decade (from 2000 on) it began to happen in many directions. The most important change was renewing of building codes (2003 – 2010) – one driving force was to harmonize the codes with European codes and Energy Performance of Buildings-directive and, of course, energy efficiency in general.

Building thermography was certified since 2003 – the reason for certification procedure of building thermographers came from contractors. There were no guidelines for the interpretation of results of thermal scanning and no recommended lowest allowable surface temperatures of structures. The level of reports was changing. The building companies and also the customers were not satisfied with the quality of the thermography reports. The credibility of thermal scanning was beginning to fade in the group of contractors.

Certification of air tightness measurers started first as an additional course for Building Thermographers in 2009 and then as an independent course, even participating also Building Thermographer-training is highly recommended. The both certification course are arranged by RATEKO (The Training Center of Confederation of Finnish Construction Industries RT)[4] it the courses have been held twice a year. After accepted examination and diploma work VTT allots the certificate.

The building trade - manufacturers, building industry in general and big building owners began to pay attention to air tightness as a part of energy efficiency – one of the strongest driving forces is the tightening requirements.

1. ENERGY PERFORMANCE OF BUILDINGS-DIRECTIVE AND THE CHANGING BUILDING CODES

1.1 The building codes

There have not been requirements of numerical values dealing with air tightness in Finland before 2008. Requirements of energy performance calculations caused changes in building codes 2008, then 2010 and the newest version coming 2012 [5]. The first guideline values were published in the building codes in the year 2007 (D5: Calculation of energy consumption and heating capacity of buildings. Instructions 2007), table 3 [6]. These values represent “typical values for various buildings depending on the method of construction and implementation” – it was a guideline, not a requirement. D5 is now going to be renewed, and also q50 values will be added (2012) to the table (marked by *).

Typical air tightness for various buildings

Goal of air tightness	Details	Air leak number n50 (1/h)	Air leak number q50 (m3/h,m2)*
Good	Special attention paid to air tightness of joints, junctions and seams in planning and in building site (installation and control)	One-family houses 1, 0 …. 3,0	1,0 … 3,0
		Offices, apartment houses 0,5 … 1,5	1,0 … 4,0
Average	Customary design, installation and control	One-family houses 3, 0 …. 5,0	3, 0 …. 5,0
		Offices, apartment houses 1,5 … 3,0	4,0 … 8,0
Poor	No exact attention paid to air tightness in planning and in the building site	One-family houses 5 …. 10	5,0 … 10
		Offices, apartment houses 3 … 7	8,0 … 20

Table 3. Typical air leak values according to Finnish Building Codes (2007), (2012)*

From the year 2007 the buildings must have energy efficiency calculations, which requirements are now part of Building Code Book. This is based on European Performance of Buildings Directive. This new building code took the air tightness into account when defining the energy efficiency of a building. This part of the building code has been renewed twice; according the new energy performance code from July 2012 [5], air leak value q50 cannot be more than 4 m3/ (h·m2). Better air tightness can be shown by measurements. The air infiltration must be calculated in compensation calculations based on air leak value 2.0 m3/ (h·m2). Air tightness measurement standard SFS-EN 13829 [3] is presented in the building code.

Air tightness value lower than presented above can be proved by measuring or by other procedure. In apartment houses air tightness can be shown by measuring at least 20 % of the number of apartments. The measurements can be carried out also using the own ventilation system of the building. In such a case not more than 25 % of the heated net floor area can be excluded from the measurements. If air tightness has not been evidenced by measurements or by other methods, the value q50 = 4 (m3/ (h·m2) must be used.

In new building code an E-value will be determined for the heated net floor area, describing the annual total energy consumption (kWh/m2). This value cannot be exceeded. For instance, E-value of new apartment house is 130 kWh/ (m2·a), for office building 170 kWh/ (m2·a) and for commercial building 240 kWh (m2·a). These values are the maximum values as a prerequisite of building license [5].

The air leak flow was calculated in earlier version of energy efficiency calculations dividing n50 by the factor 25. The air leak flow q_v (m3/s) is calculated now by following formula:

$$q_{v,vuotoilma} = \frac{q_{50}}{3600 \cdot x} A_{vaippa} \qquad (1)$$

q_{50} = the air tightness of the building envelope, m3/ (h·m2)
A_{vaippa} = the area of building envelope, m2
x = coefficient

For one-storied building	35
For two-storied buildings	24
For three- and four storied buildings	20
Five-storied and higher buildings	15

3600 = coefficient which converts air flow from the unit m3/h to the unit m3/s

1.2 Effect on improved requirements

These new requirements have caused the enormous boom of air tightness tests – in energy efficiency calculations one will have good advantages to show low air tightness values. Only unclear expression is “by other methods” which has not been explained. It gives some possibilities of loopholes.

Testimony of increased concern of air tightness is the certification procedure of air tightness measurers. Some manufacturers of pre-fabricated houses have launched air-tightness programs, which mean that main part of the production must be tested. Many vocational schools have blower-door equipment and hand-held infrared cameras in use. The big building owners, construction companies, manufacturers, educational institutions and other interest groups have paid more attention to air tightness – it is one factor in improving energy efficiency. Lot of new production has been measured. During last 5-7 years many new service providers has come into the business.

2. RESULTS OF AIR-TIGHTNESS MEASUREMENTS

2.1 Background

There is no covering statistics concerning air tightness of different buildings, building types or data classified by building age. Some relatively large studies have been carried out, anyhow, during last 10 years. The common trend is that air tightness of buildings, especially one-family houses, detached houses and row houses has improved significantly compared with the previous situation and especially if we compare the results the available material collected 20 -30 years ago. The trend has been progressive, but it has turned now quickly to better direction.

2.2 Recent material

In the following tables and figures some results are introduced, collected for the publication "Measurement of the air-tightness of buildings" by Sauli Paloniitty, HMK University of Applied Science [6], which will be published during the spring season 2012. The material has been collected mainly from certified air-tightness measurers, but also some prefabricated house manufacturers and construction companies have given their results for this book. The file includes mainly new or newish buildings, but there are some dozens of older buildings among them (table 4).

Number of the targets

Building type	number
One-family houses	335
Apartments, row houses	110
Apartments	53
Multi-story houses (residential)	59
Others, < 4000 m3	48
Others, >4000 m3	35
Total	640

Table 4. Statistics of measured buildings

The average and the range of air leak values are shown in figure 1. One can draw following conclusions based on the results:

- the results of one-family houses vary a lot, their n50 and q50 results are equal – variation also caused by the old building stock in the material
- also the results of row house apartments and apartments of residential house apartments vary relatively much, caused by quality of construction and the frequency of wood constructions
- results of apartment buildings and big buildings are good, caused by stony constructions (and by the measurement method of the whole building), the results are mainly from new or newish buildings

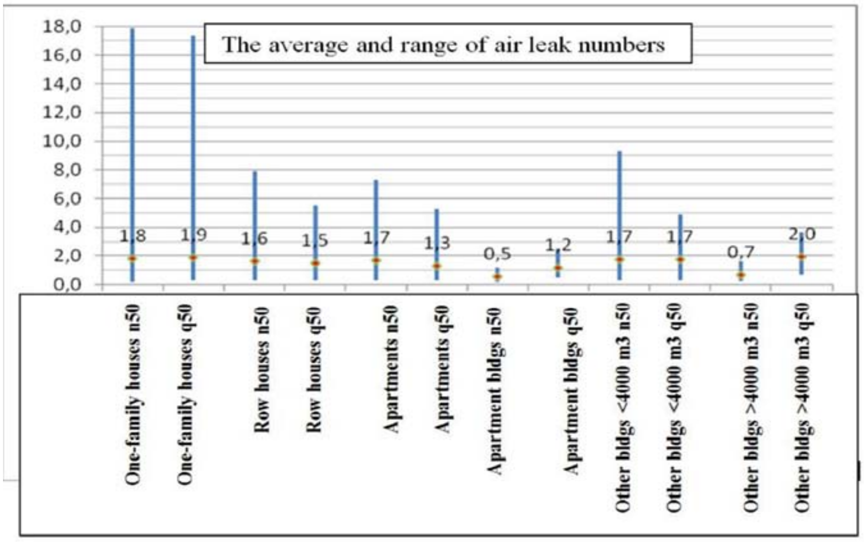

Figure 1. Average air leak values

In this material the air tightness of one-family houses built before 1999 varies relatively on the wide range (older buildings). Average n50-values were 7 – 8 1/h and q50-values were 8 – 8, 5 1/h, higher values representing 2-story buildings. The number of houses was 23. Also according the results of this material it seems that wood constructed one-family houses are leakier than the other type of houses. There are also results from new houses which doesn´t support these outcomes.

When air leakage is reported based on air volume (n50), it favors big buildings. The area of the building envelope doesn´t increase quite often related to the building volume. Also the number of leak points (corners, lead-ins) of bigger buildings is close to the ones of smaller buildings. If the air leak number n50 of a cubical-type building is 1 1/h, the air leak number related to area of the building envelope is 2 when the volume is 2000 m3 and 3 when the volume is 6000 m3. The following figure 2 shows the relation of n50 and q50 of different type of buildings.

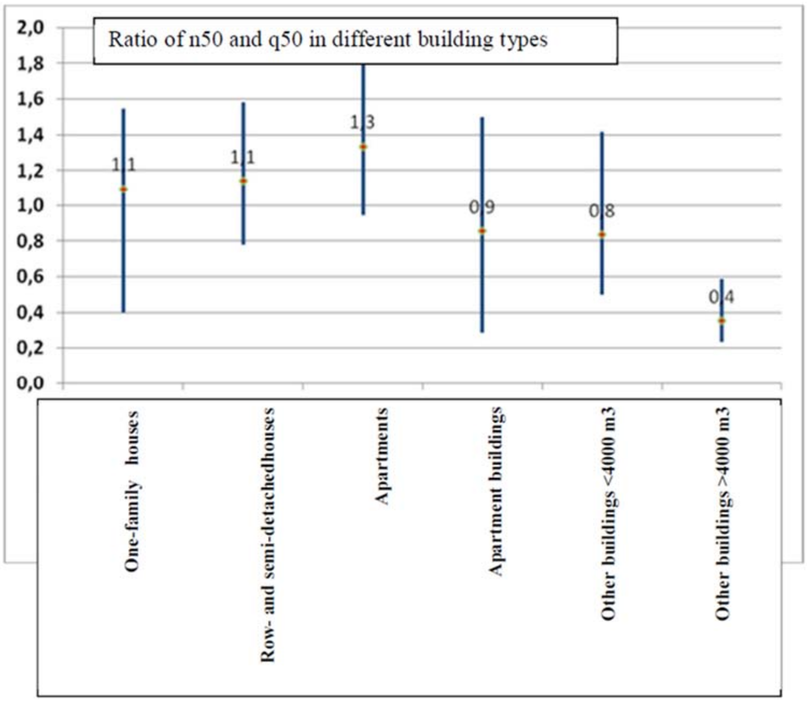

Figure 2. n50/q50 ratio in various building types

Tampere University of Technology (TUT), Department of Building Physics has studied over 10 years the air tightness of buildings and also published research reports dealing with solutions of tight constructions. Tampere University of Technology has also made other research and development work connected with building physics, energy performance of buildings and air tightness, e.g. guidelines of airtight structures. Here is introduced some results of studies realized during 2001 – 2008 [7], [8].

The study carried out by Tampere University of Technology (AISE-project) contained 70 different types of one-family houses, built between1996 – 2006 and 56 apartments in multistory houses (2 – 9 floor buildings). Tables 5 and 6 show the main results.

Air tightness	**Mean value, [1/h]**	**Min**	**Max**
Air change rate at 50 Pa neg. pressure (n50-value)	3,30	0,4	15,1
Air change rate at 50 Pa pressure (n50-value)	3,46	0,5	17,2
Air change rate at 50 Pa, mean value/, (n50-value)	3,38	0,5	16,2
Number of buildings (1996-2006)	70		

Table 5. Statistics of measured buildings (AISE-project, one-family houses)

Air tightness	**Mean value, [1/h]**	**Min**	**Max**
Air change rate at 50 Pa neg. pressure (n50-value)	1,6	0,3	5,3
Air change rate at 50 Pa pressure (n50-value)	1,9	0,3	6,2
Air change rate at 50 Pa, mean value/, (n50-value)	1,7	0,3	5,5
Number of apartments	56		
Floor area, m2	72,5	35	138

Table 6. Statistics of measured apartments (AISE-project, multi-story houses)

The air leak number n50 at a positive pressure drop seems to be > n50 (negative pressure drop) in most cases.

During 2008 – 2009 VTT has measured lot of new building projects of various building companies (apartment buildings) [9]. The apartment-specific air leak numbers of apartment houses have varied 0.3 – 1.0 1/h. The leak points have been concentrated in window weather-strips, balcony doors and the doors to the stairways. In older stock of apartment houses the apartment specific results can be as much as > 2.0 1/h. The air leak numbers of stairways in new production have been > 1.0 1/h, often in the level of 2 – 3 x the leak numbers of single apartments. A special attention should be paid to the air tightness of staircases (figure 3).

The manufacturers of one-family houses and row houses had contracted out measurements of new buildings, because of energy efficiency calculations. The builders, who have paid a special attention to the structural details affecting air tightness, have reached the level n50 < 1.0 1/h in one-family house targets, i.e. to the level of multi-storey house apartments. It means, accordingly, that first-class tightness level can be reached by a "conventional", but careful construction (figure 4). The best measured value n50 at the moment is 0,1 1/h (maybe this is the a sufficient limit).

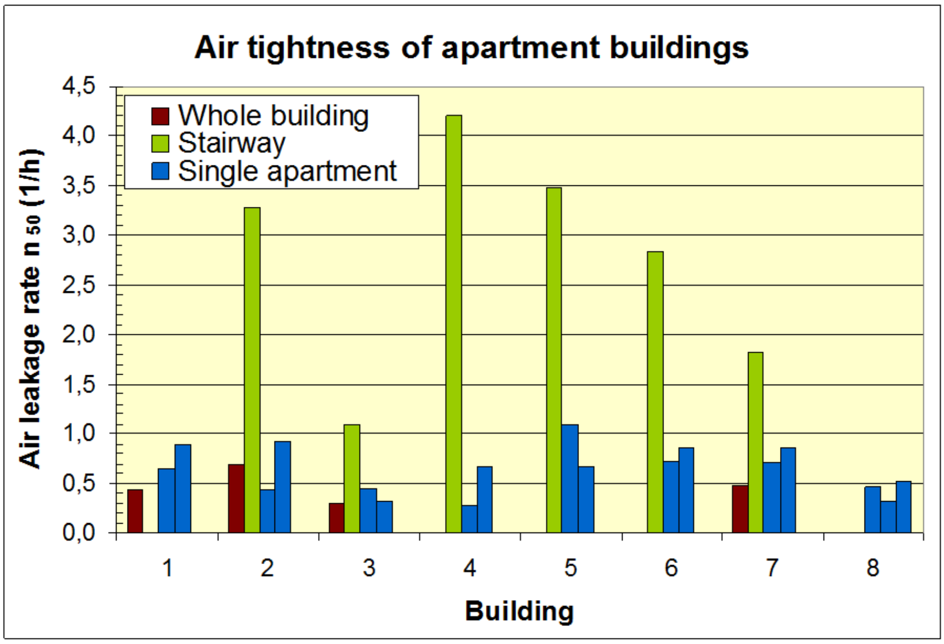

Figure 3. Results of new apartments

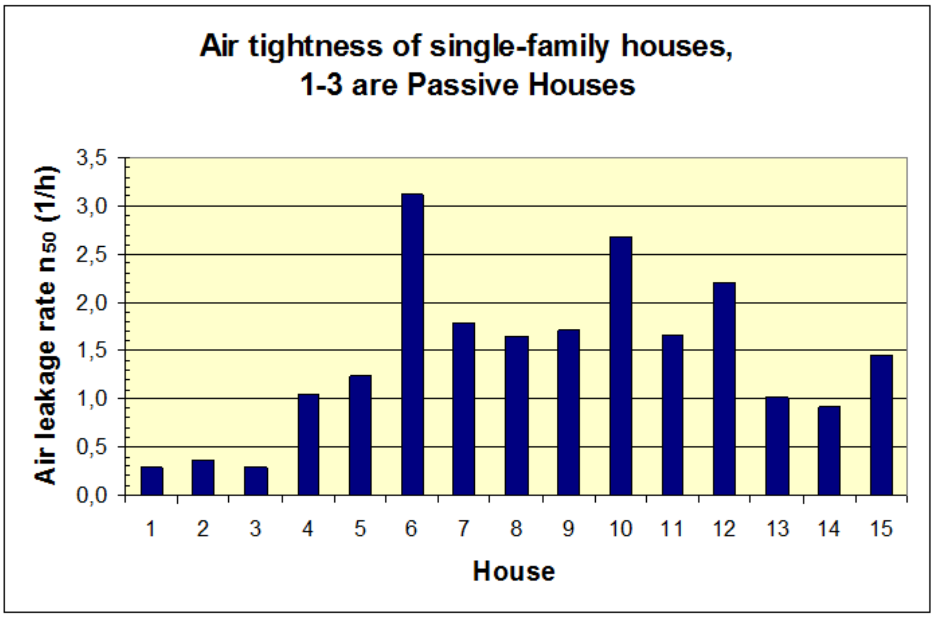

Figure 4. Results of new one-family houses

In the other presentation some achievements has presented, based on systematic quality control. The passive house level can be reached by careful work and advance design of details.

2.2 Earlier results

VTT studied in 1981 air tightness level of some buildings [10]. The data collected the then VTT Building Laboratory (the total number of buildings was higher) included 42 one-family houses with various materials. Insulation material was mineral wool (32) and sawdust (12). The sample was relatively low and the results are therefore only suggestive. The air leak numbers concentrated between 7-9 1/h (Table 7). This was the first study dealing with the air tightness of one-family buildings except some single cases.

Type of building	Targets	n_{50} (mean value)
One-family houses, built before 1973	7	7,9
One-family houses, built after 1973	9	6,6
Row houses , before 1973	1	9,3
Row houses, after 1973	15	9,8
Log houses	10	9,7

Table 7. Air leak numbers according to building type (1981)

Type of building	Targets	n_{50} (mean value)	Lowest	Highest
One-family houses	56	5,3	1,6	18
Row houses , apartments	102	5,6	1,7	14,9
Log houses	13	10,7	5,3	14

Table 8. Air tightness of one-family houses 1981-1988

Table 8 shows the results of 171 one-family houses during 1981-1998 [10]; also collected by VTT Building Laboratory. Main part of the houses has been reclamation cases. This means that the results can be worse than average or distribution of leak points has concentrated in that way, that it caused draft problems. Age of the buildings varies. Biggest group of one-family houses was between 3 - 4 1/h and of row houses between 4 – 5 1/h.

There are also data available for Finnish Housing Exhibitions [11], which shows that air-tightness has been improved and more attention has been paid to that topic. In the latest exhibition (Housing Exhibition is arranged every year) air-tightness related things have been on the frame.

2.3 Mesurement problems

Every measurement includes also measuring errors [12]. The measurer must know the operational principles of the device used and operating range. If the measured result is doubtful, measurements should be repeated, or must be verified. If the capacity of the Blower Door-equipment is too high compared with the measured air flow rate, there is a possibility of very big measurement errors. If the result of one-family house decreases to the level << 0.5 1/h, the achieved result should be verified, if possible. Very often one cannot have any measurable result in small and tight apartments by small pressure differences. When the pressure drop increases > 20 Pa, the air flow can be measured – depending on the case. It is not necessary to reach 50 Pa pressure difference if there are at least 3 reliable measuring points available. The weather conditions (wind and outdoor temperature) are more important factors especially when high buildings are measured. The stack-effect has an effect on results.

The measuring errors include errors in air flow measurements and errors in measuring building magnitudes [6]. Also tightening can cause some errors (defective tightening). If the building volume and area of building envelope has been measured from construction drawings, the error can be 10 %. The total tolerance using commercial blower door equipment is typically 3 % … 10 %. If the ventilation system of the building is used, the error is 10 % …. 20 %. The building code allows also the use of ventilation system of the building for measurements.

The use of the building ventilation system is becoming more common. In case of large buildings it is a practical way to determine the level of air tightness. The problem is the accuracy of results (one must know the tolerance) – if the result is very close to the required value, measurements could be repeated and verified using blower doors, if possible.

3. AIR TIGHTNESS AND HEATING ENERGY CONSUMPTION AND INDOOR CONDTIONS

3.1. Energy consumption of uncontrolled ventilation

Many calculation tools are in use to evaluate the impact of air tightness on heating energy consumption. There is no larger measured data or statistics available, in which the normalized heating consumption figures would have been compared with tight and leaky buildings.

Calculations show clearly how the energy consumption decreases when building are tighter; if we emphasize only energy consumption, there is a level under which the benefit of energy saving will be hidden by other factors. The next table 8 shows how air tightness theoretically impacts on energy heating energy consumption [12]. The structures have been estimated to be at the reference level presented at Building Code. In the table the effect of tightness can be seen when reference level n50 2 1/h and 4 1/h has been used.

Air leak value, n_{50}, 1/h	**Energy Consumption, % related to reference level**	**NB**
2,0	Reference level	
4,0	+ 9	
1,5	0	
1,0	-4	Low energy house
0,6	-6	Passive house
0,3	-7	Recommendation for passive house
0,1	-8	Best measured target
4,0	0	Annual heat recovery efficiency 45 % → 61 %
4,0	Reference level	
2,0	-9	
1,5	- 11	
1,0	-13	Low energy house
0,6	-14	Passive house
0,3	-16 %	Recommendation for passive house
0,1	-16 %	Best measured target

Table 8. Calculations on air tightness and heating energy consumption (one-family house)

When air tightness value is < 1, 0 1/h, savings are not so significant, but good air tightness will eliminate moisture risks. If the value is 4 1/h and the annual efficiency of ventilation system will be improved from 45 % to 61 % (16 %-units), we will get the same result than with value 2 1/h (tightness compensation) If air tightness is 4 1/h, value 2,0 1/h gives 9 % saving. If air tightness value is > 4 1/h, there are significant differences in energy consumption, comfort and in possible moisture risks compared with tight building.

The other example is from a library (part of a school facility). Air tightness of the library was very poor, at the level 13 1/h before renovation.

n50, library, 1/h	Specific energy consumption (normalized), kWh/m3	change, %
13	65	
6	55,4	15
3	51,5	7
1	49	5

Table 9. Calculations on air tightness and heating energy consumption (library)

The change from the level 6 1/h to 1 1/h decreases 12 % of heating energy consumption. Change from 3,0 1/h to 1,0 1/h decreased energy consumption only 5 %. The most important thing in case of existing buildings is to get the building into a level, which is realistic compared with the renovation costs and reasonable compared with the energy consumption. The moisture and draft risks still exist in this particular case.

3.2 Indoor conditions

Air tightness has an effect on energy efficiency but also on indoor conditions. If leaky patterns have concentrated in relatively small area, cold surface temperatures and cold air flow can cause draft. Draft is mainly compensated by increasing indoor temperature. Also external water penetration and air infiltration can cause indoor air quality and healthy problems and moisture risks, as well as condensation of water vapor from indoor air.

4. DURABILITY OF AIR TIGHTNESS

There are no covering data about durability of air tightness – some single tests have been made. Sealant materials have been tested in the field and laboratory conditions. As a thumb rule one can say, that tight buildings remain relatively tight, but leaky buildings can be degraded furthermore. When aiming toward tight structures, the material selection plays significant role. Also how the structural details have been designed and implemented. Multiform and complex wood constructions may include a risk if the implementation is not properly done.

5. CONCLUSIONS

The biggest problem is how to improve the air tightness of existing building stock, because new building covers only 1-2 %/year/from the total building stock (or even less). The improvement of air tightness in general is a positive issue, also when it has led also up the systematic approach of better design, careful installation and product development [13].

There is still lot of open questions, especially

- How to measure the air tightness of big and tall buildings,

- What is the real connection between air infiltration and air tightness value and
- Which levels we will accept in the future
  and
- How to motivate and train the employees
- How to increase comprehension of building physics

The results have also shown some problems in the measurement technology.

The air tightness measurement is one part of building commissioning and quality control procedure, when the factors affecting tightness must take into account better than at present already in the design and planning stage. Many enterprises have already started development work, in which they aspire to create a procedure, which will cover both the planning and implementation phase. In design phase those building parts and structural details will be defined, the realization of which will be addressed to the construction site. The final performance of the building envelope depends totally on that fact only, how the things in question are done and how the details have been carried out in the working site.

In different connections there has been discussion about the tightness: Can the building be "too tight". The real problem has been mostly about defective ventilation. When structures have been tightened but the ventilation system has unchanged (in case of natural ventilation), operational preconditions of ventilation system has been decimated. If the building has equipped with mechanical exhaust ventilation, calking of the structures has increased the negative pressure drop and part of supplied air has come through leak routes. This causes draft. Reclamations of indoor air quality and thermal comfort are still general, even the air tightness of buildings has improved, according to the available data. There are many factors governing indoor conditions and thermal comfort, and too often one pay attention to one single factor only.

The indoor conditions are the sum of the performance of

- building envelope
- heating system
- ventilation system
- cooling system
- building automation system
- internal and external loads, weather condition, location
- use and maintenance

Many organizations and enterprises in building trade have launched programs and increased activities to improve air tightness; good results are in evidence. There is still lack of motivation and ignorance. Air tightness is part of building physics. New building code has set the maximum limit (q50) of air tightness for new buildings. The required value could be even lower.

ACKNOWLEDGEMENTS

Mr Sauli Paloniitty, HAMK University of Applied Sciences and Assoc. Prof. Juha Vinha, Tampere University of Technology with his colleagues Ms Anu Aaltonen and Ms Elina Manelius have given material for this presentation. Mr Juha Krankka, RATEKO, Mr. Markku Hienonen, Building Supervision Office, City of Oulu, and Mr Ilpo Kouhia, VTT have communicated with the authors and commented the topic and the content.

REFERENCES

[1] Sisäilmastoluokitus 2000 (Classification of Indoor Environment 2000). www.sisailmatieto.fi, replaced by

[2] Sisäilmastoluokitus 2008 (Classification of Indoor Environment 2008). SIY Sisäilmatieto Oy, www.sisailmatieto.fi; RT-07-10946, Rakennustietosäätiö RTS 2008 (The Building Information Foundation RTS, Helsinki, Finland) http://www.rts.fi/english.htm

[3] SFS-EN 13829 (ISO 9972:1996, modified). European standard, CEN 2000

[4] http://www.rakennusteollisuus.fi/en/ (website of Confederation of Finnish Construction Industries RT); http://www.rakennusteollisuus.fi/RATEKO/Koulutusohjelmat/ (website of The Training Center of Confederation of Finnish Construction Industries RT)

[5] D 3. Suomen rakentamismääräyskokoelma. Ympäristöministeriö. Rakennusten energiatehokkuus. Määräykset ja ohjeet 2012. (D 3, Finnish building codes. Ministry of Environment. Energy efficiency of buildings. Requirements and instructions 2012. Ministry of Environment 2011)

[6] Paloniitty, Sauli. Rakennusten tiiviyden mittaus (Air tightness measurement of buildings). Manuscript, to be published 2012. Rakennustieto Oy. www.rakennustieto.fi

[7] Vinha, Juha & al: Air tightness, indoor climate and energy economy of detached houses and apartments. Research Report 140, Tampere University of Technology, Department of Civil Engineering, September 2009 (in Finnish). ISBN 978-952-15-2738-8 (PDF). 148 p. + app. 19 p. http://dspace.cc.tut.fi/dpub/handle/123456789/20819

[8] Vinha, Juha & al: Puurunkoisten pientalojen kosteus- ja lämpötilaolosuhteet, ilmanvaihto ja ilmatiiviys. Research Report 131, Tampere University of Technology, Department of Civil Engineering, August 2005. (in Finnish) . ISBN 978-952-15-2747-0 (PDF)

[9] Kauppinen, T., Ojanen, T., Kovanen, K., Laamanen, J. and Vähäsöyrinki, E. Rakennusten ilmanpitävyys (Air tightness of buildings) in Indoor air seminar, Helsinki. Säteri, J, Backman, H (ed). Indoor Air Association, report 27, ISBN 978-952-5236-35-8, Loimaa, Finland 2009.

[10] Rantamäki, Jouko, Kauppinen, Timo. Suomalaisten rakennusten ilmanpitävyys mittausten perusteella. SIY Raportti 13. Sisäilmastoseminaari 1999. Säteri, Jorma & Hahkala, Harri (toim/ed.). Sisäilmayhdistys SIY. Helsinki 1999 (Air tightness of finnish buildings on the grounds of measurements). Indoor Air Association, report 13, pp.329-336. Sisäilmatieto Oy 1999.

[11] Housing Fair Finland Co-op; http://www.asuntomessut.fi/en/english-home

[12] Kauppinen, Timo. Rakennusten ilmanpitävyys. Rakentajain kalenteri 2011 pp. 123-131. (Air tightness of buildings, in the publication Rakentajan kalenteri) Rakennustieto Oy, www.rakennustieto.fi, Hämeenlinna 2010. ISSN 0355-550 X.

[13] Kauppinen, Timo &al: Energy efficiency calculations and tightness of buildings in Finland. 4th International Symposium on Building and Ductwork Air tightness (BUILDAIR). berlin 2009.

Airtightness requirements: a lawyer point of view

Rik Honoré, Honoré & Gits, Belgium

ALTERNATING LOADS – A METHOD FOR TESTING THE DURABILITY OF ADHESIVES IN AIR TIGHTNESS LAYERS

Prof. Dr.-Ing. Thomas Ackermann, University of Applied Sciences, Campus Minden,
Institute of building physics and building construction

1. Scope

In order to grantee that a building fulfills the requirements for energy saving and hygiene it is necessary that the envelope of a building is air tight. This attribute should be preserved during the whole period a building construction or a layer is in use. The loads on the envelope of a building and its connections to nearby constructions are highly influenced by the wind.
To connect sheets and foils in the air tight envelope adhesive tapes or glues are often used. For testing if these adhesives are able to work a German standard is in preparation.
This article presents the method of alternating loads for testing the durability of adhesives in air tightness layers and shows background information. Because this method describes the way adhesives work it had to be examined how loads are influencing adhesive tapes und glues and if there is a method to simulate the artificial aging under the regard of durability.

2. Loads

Roofs and walls of buildings are incriminated by dead loads, live loads, snow and wind. While the major forces resulting from this loads are carried by surface layers or the structure wind loads are travelling through a building elements. That does not mean that the wind penetrates a construction. It means that the pressure wave resulting from the wind has to be taken by the surface layers but also by the air tightness layers and its connections. Which part of the wind loads influencing a tiled roof is travelling thorough the construction to the air tightness layer was examined at the Fraunhofer institute for building physics in Holzkirchen [1].
Therefore in a section of a roof a part of the vapour control layer was removed. Instead of this layer a membrane was installed. Using a monometer box the air pressure on the internal layer could be measured. The pressure on the outside surface was calculated from the wind speed. A comparison between the outside and the internal air pressure showed that about 60 to 75% of the outside air pressure resulting from wind is influencing the vapour control layer.
As a result to this research an analysis of outside wind speeds or wind pressure is required to get information about the design air pressure on vapour control layers. Looking to the loads from wind in a more detailed way you can see that the oncoming forces are not constant but alternating. Even wind loads that seem to be constant are the sum of individual events. Besides this there are gusts from extreme wind speeds.
In order to give an example about the alternating structure of wind speeds figure 1 shows this effect at München. While the upper diagram shows an average wind (the maximum wind speed is at about 8 m/s) the lower diagram shows the wind speed from a gust (the maximum wind speed is at about 20 m/s)

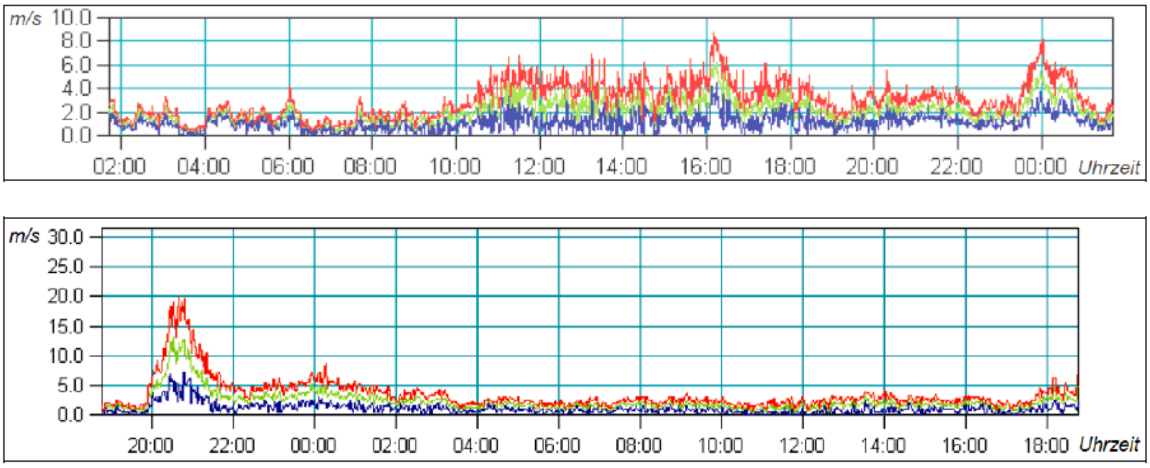

Figure 1. Alternating structure of wind

As a result from the researches on wind loads the durability of adhesives in air tightness layers has to be proofed by alternating average wind speeds (wind pressures) and maximum wind exposures like gusts.

3 Testing method

To simulate the forces from wind loads influencing the air tightness layers and the adhesives the testing method of alternating loads was developed. It represents the influence of pressure from average wind speeds and gusts during the period a construction is in operation which is about 50 years.
When using this method samples from air tightness layers including connections made from adhesives are fixed at one end while the load is put on it at the other side with a jerk.

3.1 Design loads

It was already mentioned in chapter 2 that adhesives are influenced by two sorts of wind loads: average loads showing “normal” wind speeds and extreme loads representing gusts. While average wind loads appear very often, the influence of gusts is rare. So the test with average wind loads simulates fatigue assessments while the test with gusts shall proof if adhesives are able to cope with extreme loads.
The way to simulate fatigue assessments was described by the British research institute „Building Research Establishment“ [2]. It is pointed out in this research-work that at a special place wind speeds during a period of 50 years have to be evaluated in order to find out the design wind load. Exploring the method of alternating loads daily average wind speeds were examined. Due to the BRE digest the design load is defined by the wind speed that is exceeded once in 50 years (2%-fractile). Therefore it was used the method of Gumbel distribution. The calculation was made at thirty places in Germany using wind speeds from a period of fifty years which came from the German weather service.

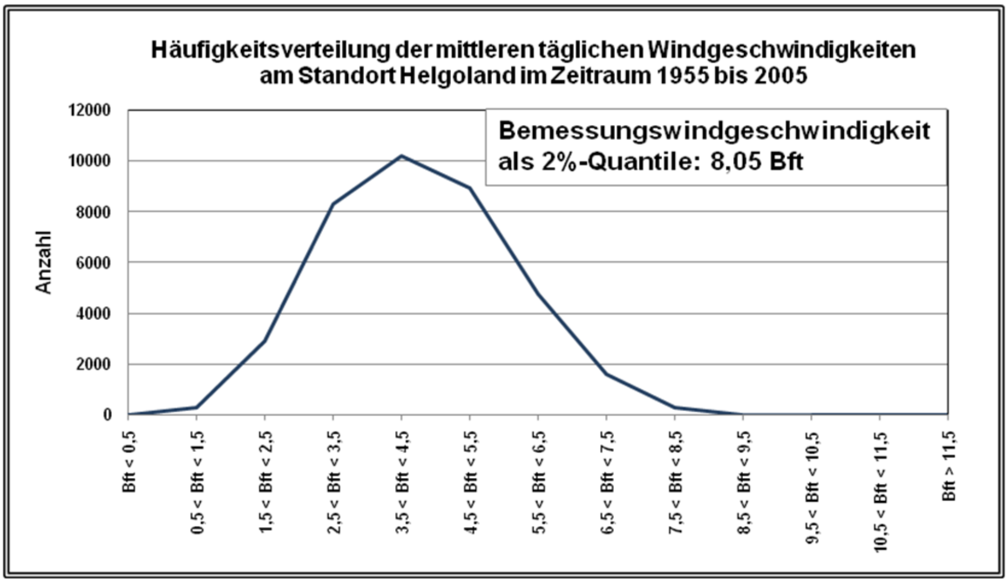

Figure 2. Frequency of average daily wind speeds

Using this method to analyse average daily wind speeds a design load could be calculated at Helgoland from 8.02 bft, at List on Sylt from 7.75 bft and at Hof from 7.31 bft. The maximum wind speed at the examined places was 51 m/s. That is equivalent to almost 16 bft.
By using this design wind speeds the weights shown in table 1 were calculated. The frequency was taken from the BRE digest.

Simulation of fatigue assessment			
Number of alternating loads per cycle	**Number of cycles**	**Part of maximum load**	**Load per sample**
		[%]	[g/25mm]
1	**5**	**90**	**900**
960		**40**	**400**
60		**60**	**600**
240		**50**	**500**
5		**80**	**800**
14		**70**	**700**

Table 1. Alternating loads and cycles for fatigue assessment

In addition to fatigue assessment the influence of gusts is tested by using weights shown in table 2.

Simulation of maximum loads			
Number of alternating loads per cycle	**Number of cycles**	**Part of maximum load**	**Load per sample**
5	**1**	**100**	**2000**
300 seconds		**100**	**2000**

Table 2. Alternating loads and cycles for gusts

3.2 Testing appliance

Because no appliance existed, a new one had to be designed. As shown in figure 1 the influence of wind is rather short. So in order to have a testing method to simulate the influence of wind on adhesives the load is put on it with a jerk.

Figure 3. Testing appliance

The loads are situated on a plate which is lifted by an eccentric disk. At the high point the plate drops down and the loads are influencing the adhesives with a jerk.
A sample does not fulfil the test if the weight is permanent on the plate.

3.3 Artificial aging

In order to find out if an adhesive is able to withstand the influence of wind during the whole time it is in use the samples are artificially aged.
This is done by heat and moisture. The conditions therefore are a temperature from 65° C and moisture contempt from 80%. Information showing the correlation between natural and artificial aging are taken from [5] and [6]. The results are shown in table 3.

Artificial aging at 65 °C / 80 % r.F. in days	Natural aging following ASTM D3611-89 [5] in years	Natural aging following SATAS [6] in years
21	10,5	3
40	20	5,7
80	40	11,4
120	60	17,1

Table 3. Correlation between artificial and natural aging

A precise correlation between natural and artificial aging for adhesives in air tightness layers by using [5] and [6] is not possible because the ASTM method was only used by testing complete rolls of adhesive tapes (no samples) and the SATAS method was used by medical plasters.

4. Samples

The samples which have to be tested are 25 mm wide, the glues are 1,0 mm thick. The reference material to be connected by adhesives is a PET-folio or a combination between a PET-folio and beech wood.

5. Results from alternating load tests

In order to validate the method of alternating loads nine adhesive tapes and seven glues were tested.

5.1 Adhesive tapes

Three from nine adhesive tapes failed the test. Two products failed during the fatigue assessment one when being loaded with weights from gusts. In all three cases the glue and the basic material were stretched.

5.2 Glue

One glue failed the alternating load test. The glue material was stretched so very much that in the end the weight it stood permanent on the plate

6. Summary

Alternating loads are describing a method for testing the durability of adhesives in air tightness layers by simulating natural conditions.
To simulate the influence of wind adhesives are loaded by weights in a jerk. The weights have been found by a statistical research of wind speeds during fifty years at thirty positions.
In order for not only testing the resistance of adhesives by alternating loads but for testing the durability too the samples were artificially aged.
Tests with nine adhesive tapes and seven glues showed that three tapes and one glue failed the test. That means that such a test method is needed to guarantee the quality and durability of adhesives.

Literature

[1] **Fraunhofer-Institut Holzkirchen** „Untersuchung von geklebten Dampfbremsfolien im Dach und Übertragung der Ergebnisse auf Kleinprobekörper unter Berücksichtigung der Kaltflusseigenschaften von Dampfsperren-Klebedichtmassen“, Prüfbericht P17-128.1/2007

[2] **BRE Digest 346** „The assessment of wind loads – Part 7: Wind speeds for serviceability and fatigue assessment”

[3] **DIN 1055-2:2005-03** “Einwirkungen auf Tragwerke – Teil 4: Windlasten“

[4] **DIN 1055-100:2011-03** “Einwirkung auf Tragwerke – Teil 100: Grundlagen der Tragwerksplanung, Sicherheitskonzept und Bemessungsregeln“

[5] **ASTM – American Society for Testing Material** “Standard Practice of Accelerated Aging of Pressure-Sensitive Tapes” Designation D 3611-89

[6] **Satas, D. (ed.)** “Handbook of Pressure Sensitve Adhesive Technology”

CHANGES IN AIR TIGHTNESS FOR SIX SINGLE FAMILY HOUSES AFTER 10-20 YEARS

Magnus Hansén[1], Peter Ylmén[*2]

1 SP Technical Research Institute of Sweden
Box 857
SEE-501 15, Sweden

2 SP Technical Research Institute of Sweden
Box 857
SEE-501 15, Sweden
**Corresponding author: peter.ylmén@sp.se*

ABSTRACT

In this project six single family houses that are between ten to twenty years old have been tested for air leakage. Test reports regarding air tightness from when the buildings where newly constructed were compared to new measurements. Three buildings had made changes to the building envelope while the other three had original structures. The results from the measurements showed that half of the tested buildings had considerably more air leakages than when they were new but that the other half had not changed at all.

KEYWORDS

Air tightness, leakage, durability.

INTRODUCTION

A building's air tightness is very important for the energy consumption. There are several reasons for this. The first is that a bad air tightness can cause the wind to blow into the insulation and reduces the insulating ability. The second is that potential heat recovery is not fully functioning because not all the air will take the intended path through the heat exchanger, but rather through the building envelope. The last reason that leaky buildings have higher energy use is that the degree of aeration of the building will be larger for leaky buildings, especially on windy days. In addition the residents sometimes increase the indoor temperature to compensate for deterioration of the thermal comfort.

There are a number of studies showing the importance of building air tightness and opportunities for energy savings. It has been found that the infiltration losses in some cases are greater than the losses of the intentional ventilation and much greater than the heat transmission loss. This can happen when the buildings are very leaky and in exposed areas. An example from Sandberg et al (2007) shows savings of 55 000 kWh annually of an apartment block with sealed leakages in a wind exposed location.

The air tightness of a building is created by having airtight layer with airtight joints and penetrations. In many buildings the air is stopped mainly by a flexible material such as plastic. The plastic film is joined either by stapling, crimping, or by means of splice sealant or splicing tape. Both plastic foil and the joints materials age with time, which may cause air tightness of the building to deteriorate. The same applies to joints and penetrations in massive structures. The aging of materials is due to various factors such as heat, cold, moisture, sun (UV) radiation, oxygen, ozone, chemicals and mechanical stress. Furthermore, the different materials forming the airtight layer are affecting each other, e.g. by migration of plasticizer. Knowledge of how the air tightness of a building change over time is greatly needed.

PURPOSE OF THE PROJECT

The project aims to evaluate how the air tightness of buildings change over time, to show solutions that are good and durable, which are bad and should be avoided, and to spread knowledge in the industry. The project consists of two parts, one where materials are tested in a laboratory and another where existing buildings are evaluated. This article is related to the latter.

METHOD

The tightness of the buildings change over time is examined by performing leaking tests at buildings that have been previously tested and documented (10-20 years old). SP has conducted air leakage tests for a long time and from these measurements buildings were sorted where one can assume that the change in air tightness occured due to the aging of the materials (for example, may not apply to buildings with extensive renovations). It was difficult to find buildings with enough documentation from the old measurements and had an owner that would give permission to test the building. Because of this some buildings that have some later modifications were chosen, although the modifications made it harder to evaluate the change of air tightness. All tested buildings were single family houses from different building companies. The constructions were light with wooden beams and mineral wool as insulation. There were no documents with detail structure description so it isn't possible to know exactly how the system for air tightness were made in the buildings.

When the new leakage tests are made membranes, joints and penetrations are also visually investigated (when possible) and air leak detection are conducted using infrared camera and air velocity sensor.

The testing of the building envelope was performed according to European standard EN 13829:2000. Openings in the building envelope for e.g. ventilation were sealed. A door was replaced with a thick cloth that the fan and sensor was connected. Values of the pressure difference between inside and outside as well as over sensor for air flow was determined for both positive and negative pressure. For the measurement of building air tightness Minneapolis blower equipment BlowerDoor was used.

In Sweden the air leakage is measured as litre per second and square meter (l/sm²). The area is the surface for floor, roof and walls that border to outside air or rooms that's not intended to be heated above 10 °C.

THE TESTED BUILDINGS

House 1

Figure 1. The outside of House 1.

The house was built in 1990 and is a one storey house with concrete slab and mechanical supply and exhaust ventilation. The original building had a surface area of the building envelope of approximately 300 square meters giving an air tightness of 0.14 l/(sm²).

The construction work has been done on the house when the garage has been raised as high as the main building, where part of the garage is left with room for storage. After the new construction 2003-2004 the enclosing building envelope is approximately 393 m². Measurement of air leakage was performed in November 2011 and yielded a mean of 0.95 l/(sm²). General leaks were found in ceiling and floor angle along the outer walls and in the newly constructed part of the building there were large cooled surfaces and air leaks, see Figure 2 beneath.

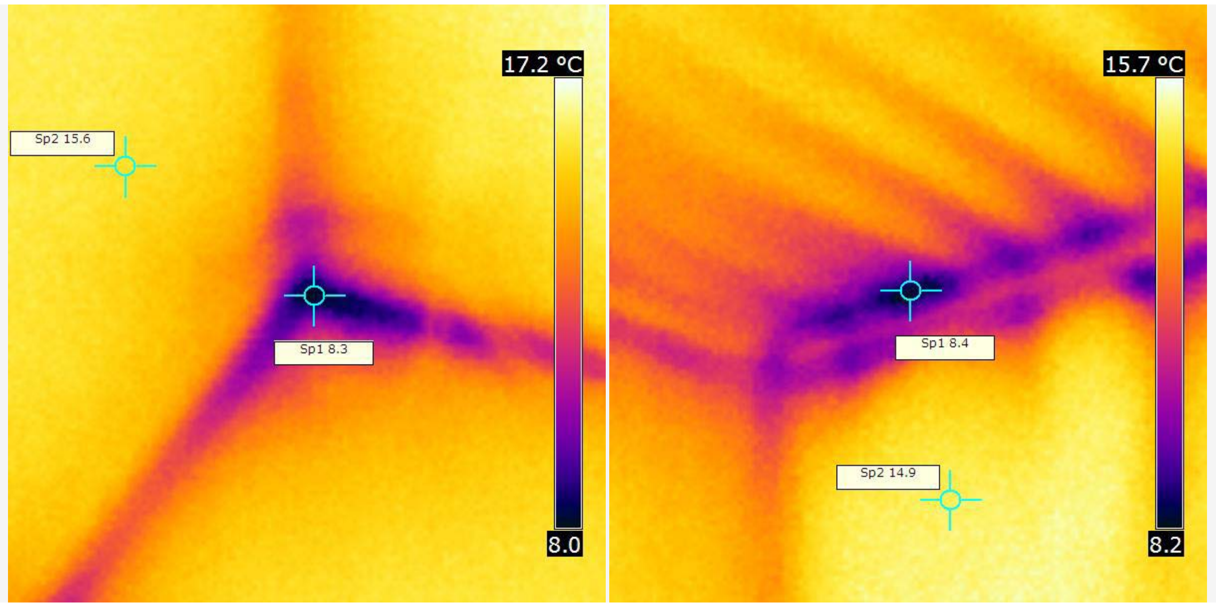

Figure 2. To the left air leakage in the floor angle and to the right cooled surface and air leakage in ceiling angle.

Overall, the air tightness has deteriorated significantly since the construction of the main building and the main reason for this is probably the newly added part of the house.

House 2

The house was built in 1990 and is a one storey house with crawl space and exhaust ventilation in the building. No changes of the structure have been made that have transformed the building envelope. The surface of the building envelope is approximately 370 m² and the measured air tightness in 1990 was 0.17 l/(sm²).

New measurements were performed in December 2011 and a measure of air leakage gave 0.77 l/(sm²). Generally there were leaks in ceiling and floor angle along the outer walls but also in the ceiling angle towards the interior walls. There were also cooled surfaces and leaks in all wall corners of the building, see Figure 3 beneath.

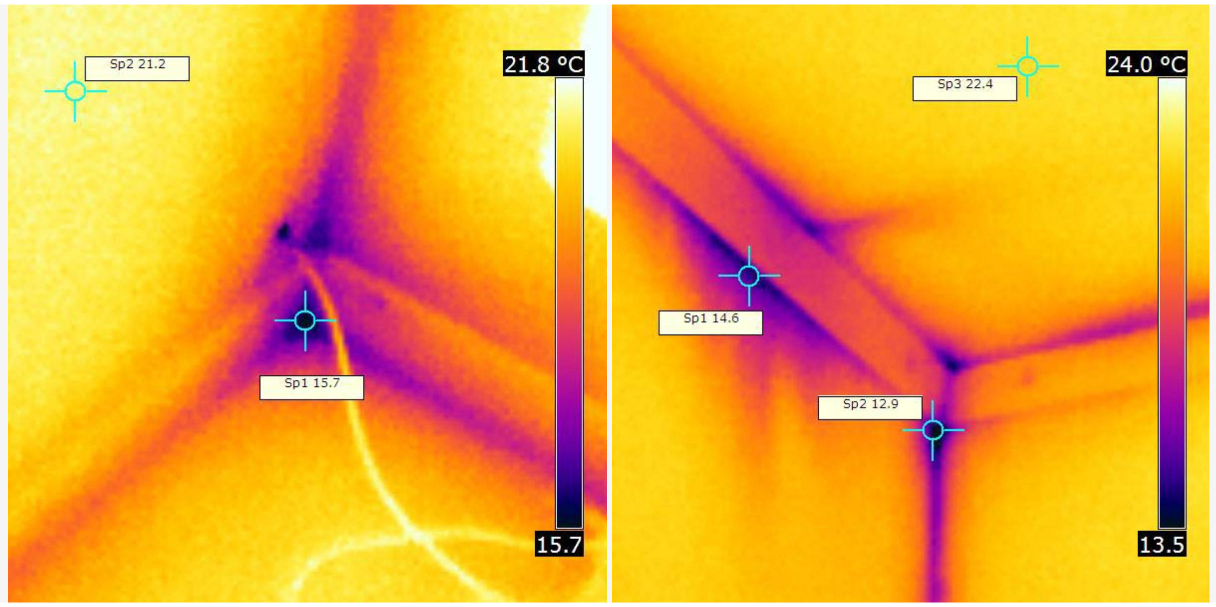

Figure 3. To the left air leakage in a corner and to the right air leakage in the ceiling angle.

There is no apparent reason for the large difference in air tightness between 1990 and 2011. It seems that the building air tightness simply deteriorated with age.

House 3

Figure 4. Picture of house 3.

The house was built in 1993 and is a one and a half storey house with concrete slab and exhaust ventilation. The original envelope surface of the building envelope is approximately 378 m² and measured air tightness in 1993 was 0.92 l/(sm²).

In 2009 a building permit was granted for the building and the house was extended 3.6 m which meant that the new envelope surface is around 474 m². At the same time, a new heat pump was installed and an additional air/air heat pump. New measurement of air leakage in December 2011 gave a reading of 1.54 l/(sm²).

It was generally air leakage along the outer wall in both ceiling and floor angle where there were also big cooled parts in the structure, see Figure 5 beneath.

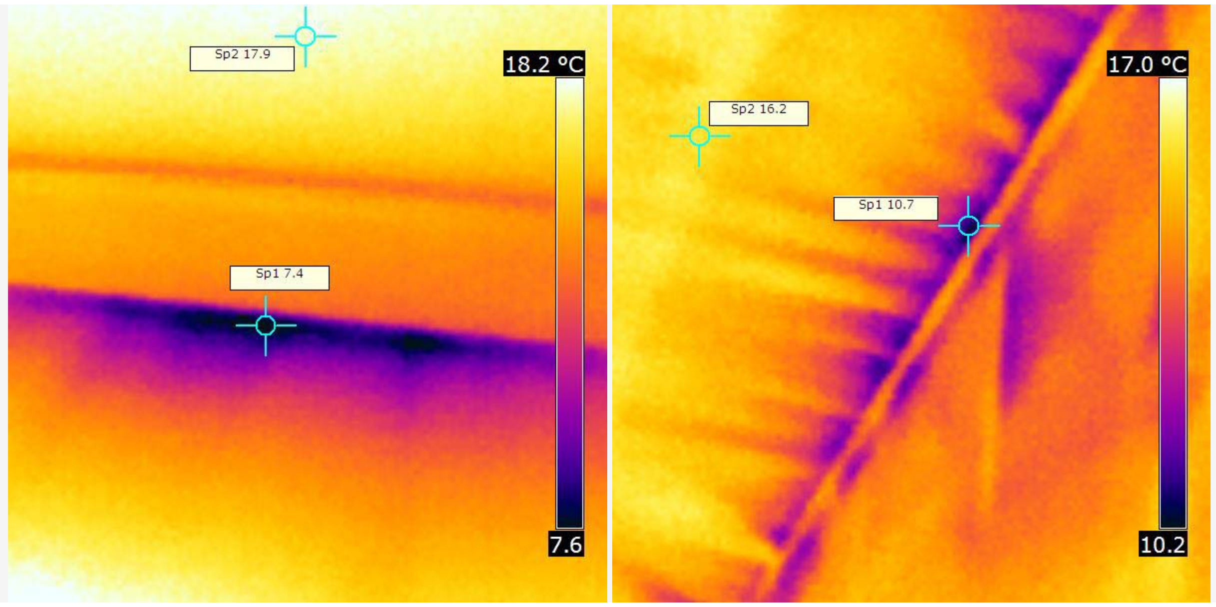

Figure 5. Air leakage from floor angle to the left and ceiling angle to the right.

Leaks were noted at the spotlights in the ceiling and the electrical installation in a storage room. On level 2 was observed air leaks in the ceiling angle along most of the outside wall and also along the transverse beams. Overall, the air tightness has deteriorated significantly after the addition to the main building.

House 4

The house was built in 1990 and is one and a half story house with crawl space and mechanical supply and exhaust ventilation. 2004 it was granted a building permit to connect level one with the garage. Initial the building envelope was about 309 m² which gave a measured of air leakage of 1.11 l/(sm²). New measurement in January 2012 gave a reading of 1.05 l/(sm²) with new envelope surface of the building approximately 380 m². Thus, the air tightness is approximately the same as 22 years ago. The investigation noted overall leakage in ceiling and floor angle where they were accessible, on both level one and two, see Figure 6 beneath.

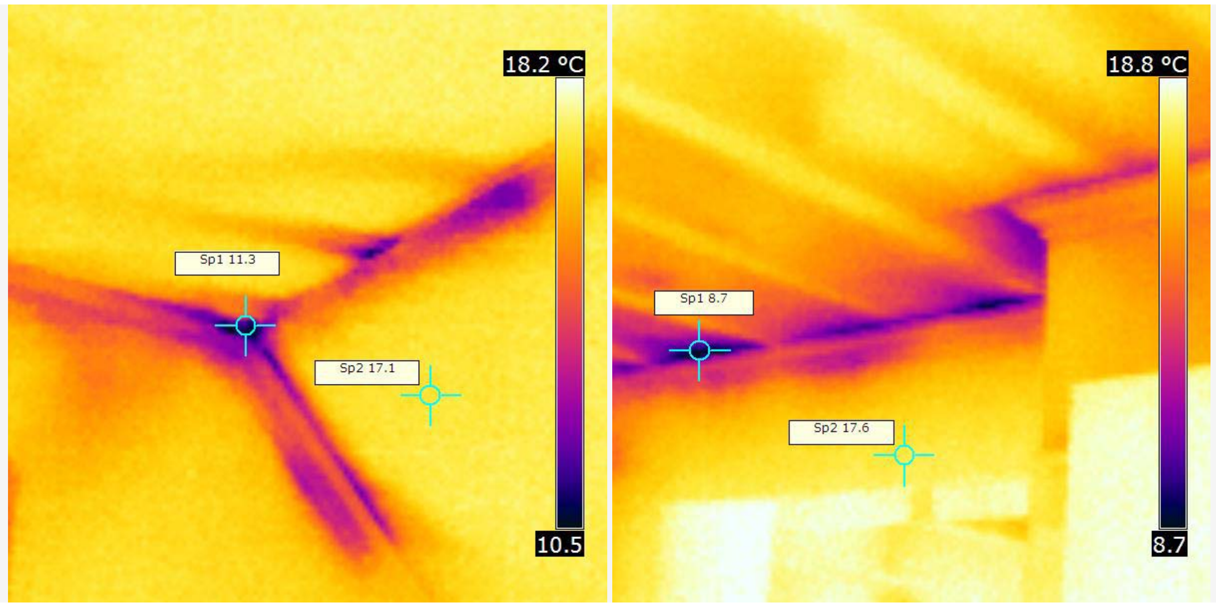

Figure 6. To the left air leakage in a corner and to the right at the ceiling.

The pipe for the stove is running through the roof on the second floor and was noted to have air leaks between the pipe and the roof.

House 5

The house was built in 1990 and is a one storey house with crawl space and mechanical supply and exhaust ventilation. No changes have been made in the structure that has transformed the building envelope. Envelope surface of the building is about 353 m² and the measured air leakage in 1990 was 0.64 (l/sm²).

New measurements were performed in January 2012 and the measure of air leakage gave 0.57 l/(sm²). Thus, the measured value of air leakage is approximately the same as 22 years ago. Overall noted leaks in ceiling and floor angle along the outer walls but also in the ceiling angels at some interior walls, see Figure 7 and Figure 8 beneath.

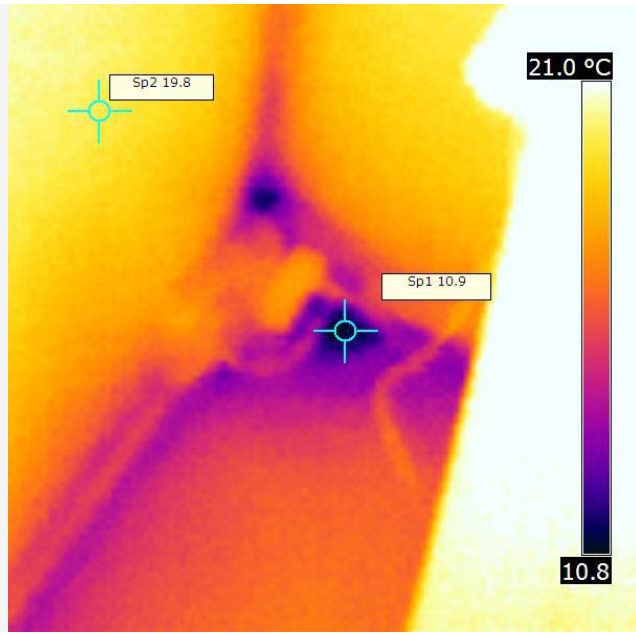

Figure 7. Air leakage in a corner at the floor.

There were also cooled surfaces and leaks in all corners of the outer walls of the building.

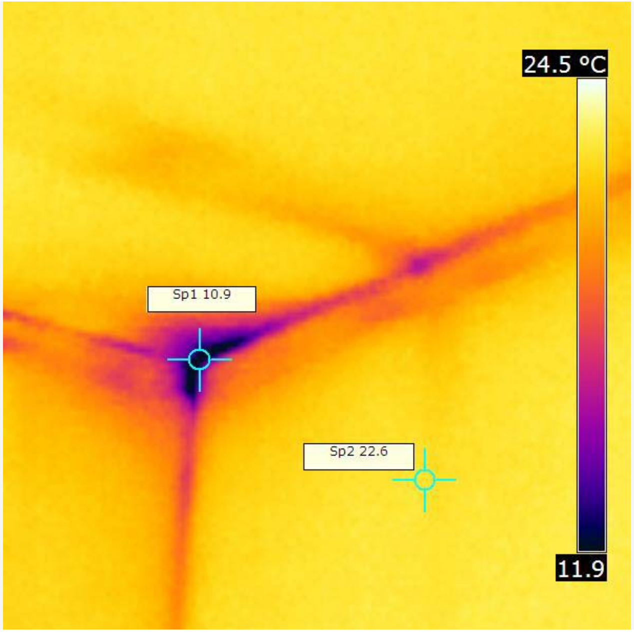

Figure 8. Air leakage in a corner at the ceiling.

House 6

Figure 9. Picture on house 6.

The house was built in 2001 and is a two level townhouse with mechanical supply and exhaust ventilation with heat recovery. The house is built to passive house standard which means that the house has more insulation than normal in the building envelope and no additional source of heat than the heat battery in the ventilation system. The apartment that includes to this study is the one who is seen to the right in figure 3 above.
The measured air leakage in April 2001 was 0.25 (l/sm²) and new measurements were performed 10 years later in January 2011, the measure of air leakage then gave 0.23 l/(sm²). Thus, the measured value of air leakage is approximately the same as 10 years ago but the difference would go beyond the measurement uncertainty.

Air leakages noted in some floor angels and one ceiling angel which can be seen in figure 14 and 15 beneath. There were also some air leakage between outer wall and windows and doors also in one electrical installation in the concrete slab. Overall we find the air tightness in this specific building good compared to other buildings we studied in this project.

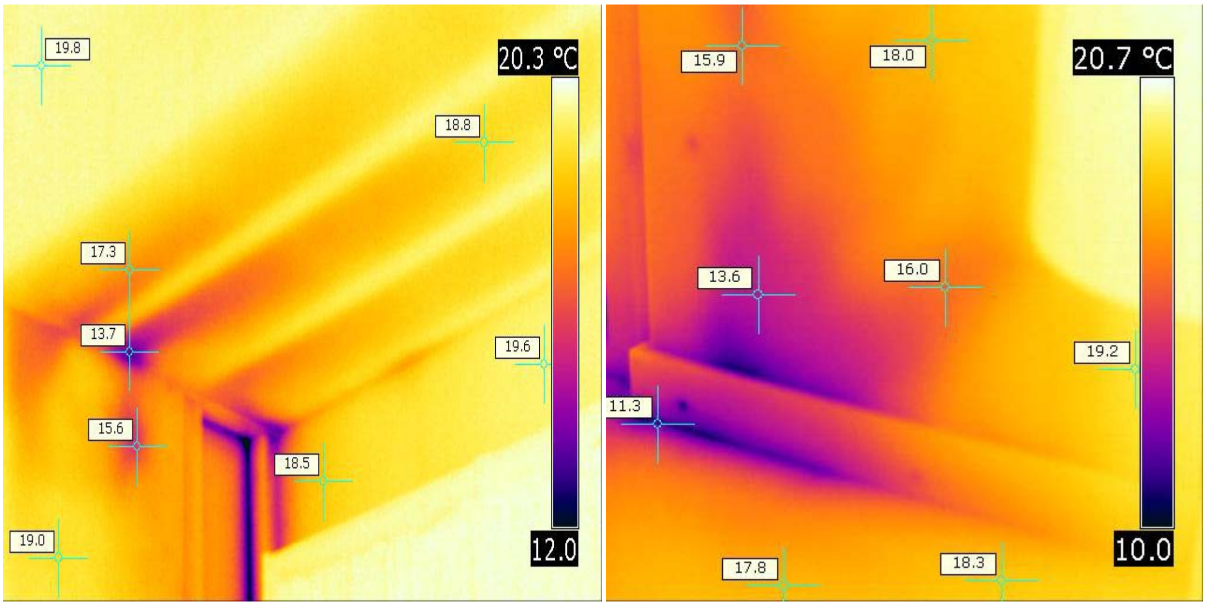

Figure 10. Air leakage in ceiling and floor angel.

CONCLUSIONS

The air leakage for the different houses is summarized in Table 1.

House	Year of construction	Air leakage when newly build [l/(sm²)]	Air leakage today [l/(sm²)]	Changes made in construction
1	1990	0.14	0.95	Yes
2	1990	0.17	0.77	No
3	1993	0.92	1.54	Yes
4	1990	1.11	1.05	Yes
5	1990	0.64	0.57	No
6	2001	0,25	0,23	No

Table 1. Summary of the houses.

House 1, 3, and 4 have had added constructions made which has led to changes in the original building envelope. The air tightness of houses 1, 2 and 3 have deteriorated considerably, while the air tightness of the houses 4, 5 and 6 is approximately the same as 22 years ago. They even show somewhat improved air tightness. This might be the cause of building movements sealing some cracks but more likely because measurement uncertainties.

The air leakage has decreased in two of the three houses where the construction work has been performed which might show the variations in construction techniques and diligence in performing these changes in the building envelope. We currently have no information on whether the construction work has been performed by professionals or has been done by the residents themselves with presumed less knowledge about construction and air tightness. Were all the construction work carried out by professionals, it would be more notable with the result in two of the three houses.

In building 2, 5 and 6 there have been no changes in the building envelope over the years and the results show that the air tightness of house 2 is significantly impaired while the air tightness in house 5 and 6 are about the same as 10 to 22 years ago. Why the air tightness has deteriorated significantly in building 2 between 1990 and 2011, we cannot answer since the houses are built by the same company, and about the same size but with the difference in the type of building and floor plan.

House 1-5 have had more or less air leakage along the outer walls of the ceiling and floor angle which is clearly visible in the buildings' wall corner. Air leaks have also been noted in the ceiling angle at some interior walls. There were also general air leaks around windows and doors. House 6 which is a 10 years younger structure was noted to have less air leakage in general, this could perhaps be due to greater awareness of the importance of airtight buildings between 1990 and 2001.

In summary, changes were made to the building envelope in three of six tested homes and two of these had increased air leakage. In the remaining three houses it has been no changes made to the building envelope, but one house has deteriorated air tightness.

Overall, after measuring the air leakage of these six houses, it shows that you can construct houses without compromising the air tightness durability. But also that it could be ruined with time if it’s not made properly.

The study also shows that the air tightness can degrade over time without making changes to the building envelope. This gives an indication that some sealing solutions becomes ineffective with time but also that it is possible to build air tight solutions that hold up over time. Which these solutions are we can’t answer since it involves destructive testing. But some modern air tightness solutions on the Swedish market are evaluated in the second part of this project as they are tested in a chamber with controlled climate for accelerated aging.

In the laboratory we are currently testing different sealing solutions and how the material age when they are influences by chemicals from other building materials, e.g. wood, concrete, zinc. A small room was constructed to get the testing at real world scale, se Figure 11. Different sealing products were applied to the walls, windows, and run troughs. There are also smaller samples placed inside the room. The room is then heated to 80 °C and 50 % relative humidity in the air to accelerate the aging process. One week a month the relative humidity is lowered to 30 % to get some mechanical movements in the structure. The result from testing will be finished at the end of 2012.

Figure 11. Pictures of the room for accelerated aging.

SEASONAL VARIATION ON WINDOW FRAME AIR LEAKAGE IN DWELLINGS

Field observations and potential impact on nearly zero energy buildings

Wouter Borsboom[1], Willem de Gids[2]

1 TNO
Van Mourik Broekmanweg 6
2628 XE Delft, The Netherlands
wouter.borsboom@tno.nl

2 VentGuide
Kievithof 3
2636 EL Schipluiden, The Netherlands
ventguide@hetnet.nl

ABSTRACT

In 1980 TNO measured the air tightness of about 21 window frames mounted in masonry or concrete walls during 3 subsequent seasons, summer, autumn or spring and winter. The seasonal effects were considerable but did not always had the same pattern. The average difference in air tightness between summer and winter was about 30 % but the maximum difference was about 120%. These measurements were about 30 years ago, nevertheless this paper is an attempt to discuss the possible consequences for air tightness measurements in nearly zero energy buildings. In case the data of this study might be used also nowadays, the time in the year we are measuring the air tightness of buildings might be very important. In fact it is impossible with a single measurement to do a correct judgement for the air tighness. Three measurements in subsequent seasons are at least neccesary to judge the air tightness well. This multiple measurements become more important in case a (financial) penalty can be given for not fulfilling the local requirements.
The data of this study suggest that one must be very careful with measured air tightness levels. Seasonal effects might change the measured result in the order up to even 100%, while the uncertainty may play also an important role.
Especially for nearly zero energy buildings this can be very important.

KEYWORDS
air leakage, air tightness. window frames, seasonal effects, uncertainty, infiltration, nearly zero energy buildings

INTRODUCTION

In 1980 TNO measured the air tightness of about 21 window frames mounted in masonry or concrete walls during 3 subsequent seasons, summer, autumn or spring and winter [1]. The main goal of this study thirty years ago was to investigate the relative importance of seams/joints between window frame and wall versus cracks of a moveable part in a window frame and the possible of seasonal weather effects. This paper is an attempt to discuss the possible consequences for air tightness measurements on nearly zero energy buildings.

MEASUREMENTS METHOD AND PROCEDURE

The measurements were carried out with pressurization where the wall and window frames were separated from the rest of the room. See figure 1. In this way the leakage through the seems/joints between window frame and wall and the cracks between the moveable parts within the window frame could be measured. During these measurements the cracks of the moveable parts were taped off to also measure their contribution in the total leakage. All dwellings in which measurements took place were normally occupied by inhabitants. In figure 1 the way the window frame was separated from the rest of the room is schematically shown.

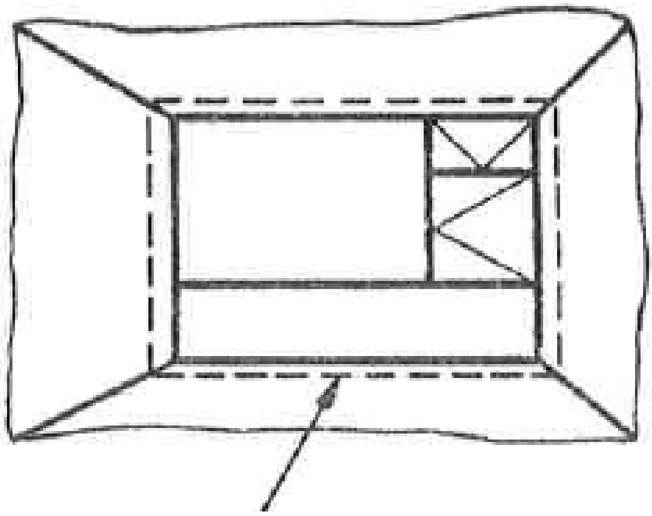

Figure 1. Separation of the window frame

The measurements were carried out during three subsequent seasons. As sometimes happens in field measurements due to a series of reasons not all measurements took place in the three defined seasons. For some window frames a season was missing.. A complete set for three seasons were established for finally 18 window frames.

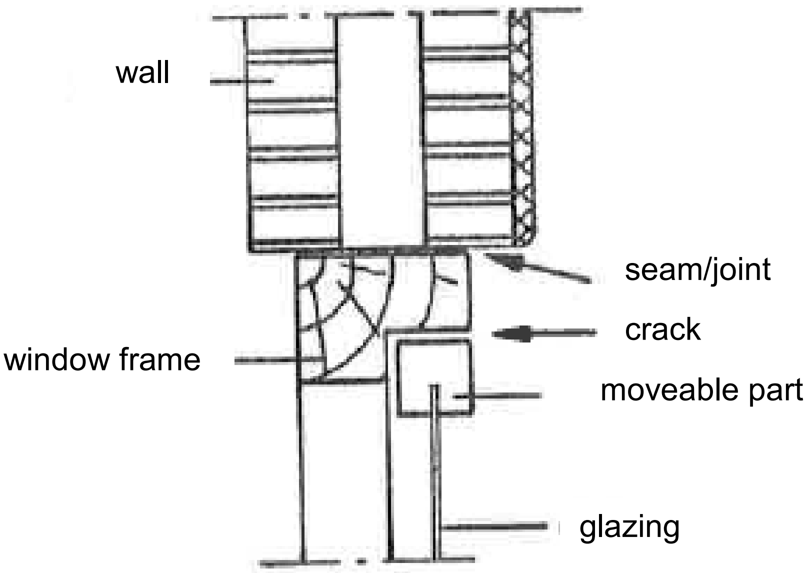

Figure 2. Window frames in wall

The pressure/flow relation was measured and expressed as normally with the equation:. .

$$q_v = C * \Delta p^n \quad (1)$$

An example of the result is given in figure 3. Both pressure and flow has their uncertainties. These are taken into account in the analysis.

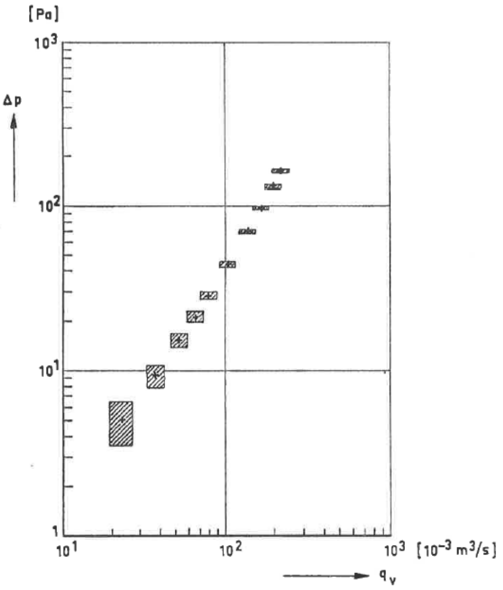

Figure 3. The relation between pressure difference and volume flow (double logarithmic)

WINDOW FRAMES

The window frames are all located in dwellings, 11 in single family houses and 7 in apartments. The window frames had different materials, 15 were constructed of wood of which 4 of hardwood. Two frames were constructed of aluminium and one of steel. The window frames had also different glazing. Only two of them were fully double glazed. In 5 window frames only the fixed parts were double glazed and 11 window frames were fully single glazing. One has to consider that these data is from 30 years ago. At that time double glazing had just entered the market in the Netherlands. Some pictures are showing the typical facades at that time. (see figures 4 and 5)

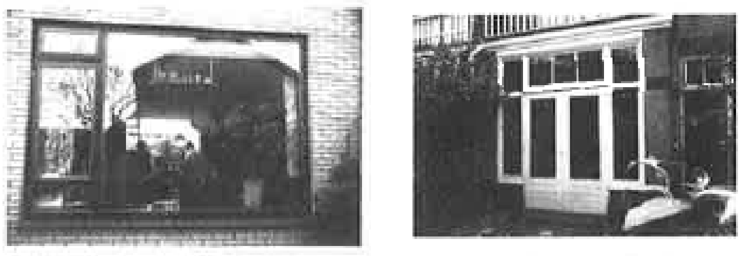

Figure 4. Window frames in single family house

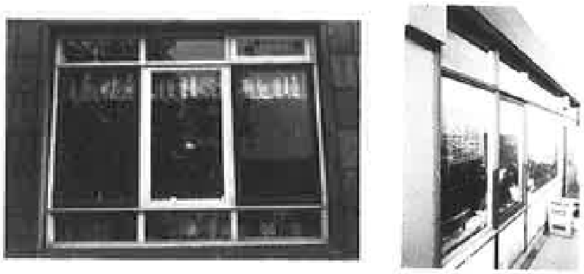

Figure 5. Window frames in apartments

WEATHER CONDITIONS DURING THE SEASONS

Deformation of walls and window frames may occur due to temperature, rain and humidity and exposure to sun radiation. From the point of energy use the summer conditions may not be important. But in case there are considerable differences between summer measurements and for instance winter measurements it might be interesting to know.
The three seasons were mainly determined in terms of temperature, but also some other weather parameters were considered.

weather season	average air temperature °C	rain	sun	sky
Summer	15 -19	dry	sunny	clear
Autumn/Spring	6 -10	rainy	no	overcast
Winter	around 0	dry	partly	clear

Table 1. Weather conditions in the different seasons.

MEASUREMENT RESULTS

All results with confidential interval are in the report presented as in figure 6.

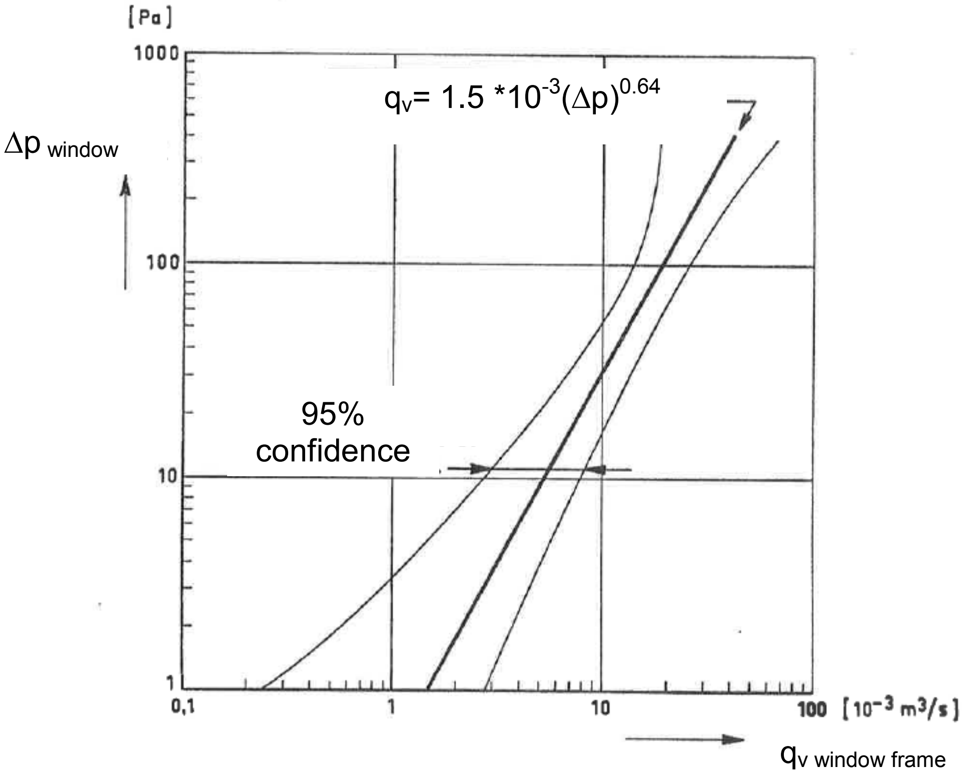

Figure 6. An example of measurement result, including 95% confidence level

The total result of all measurements carried out, are presented in figure 7.

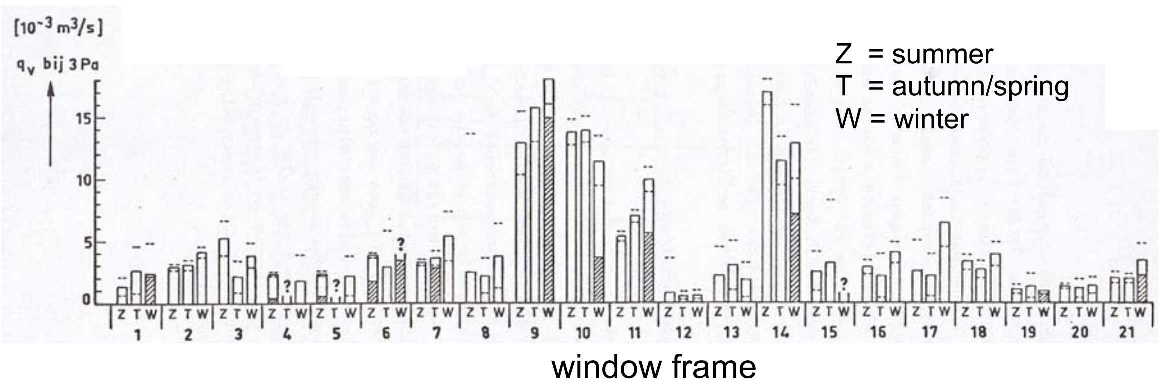

Figure 7. An overview of all measurement results at a Δp of 3 Pa

For the analysis in this paper the incomplete data sets were skipped, so 18 full sets of data were available for further analysis.

ANALYSIS

The only extra analysis which have been done for this paper was just to put all data in an excel sheet and calculate the differences for each season. The results for the winter/summer data are shown in figure 8.

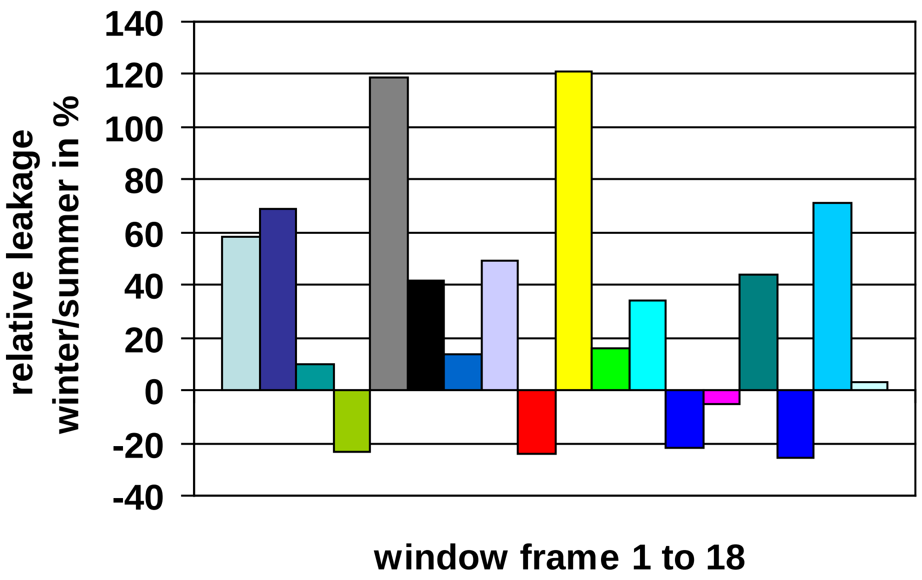

Figure 8. Relative leakage winter/summer in percentage

From figure 8 some remarkable observations can be seen. Most window frames are more leaky in winter than in summer, but there are also 5 window frames where it is the other way around, so they are tighter in winter than in summer.
The average difference between winter and summer is about 30%. The tighter window frames in winter are about 20% more air tight than in summer.The window frames which are less air tight in winter are about 40% more leak in winter than in summer. Two of the windowframes are even about 120% more leak in winter than in summer. The same data can be found for the other season. The average between winter and autum/spring is about 20%.
The effect of uncertainty can play a role in judging air tightness of nearly zero energy buildings. If one consider the 95 % confidence interval in figure 6 it will be hard to judge airtightness results within plus or minus 50%.

CONSEQUENCES

The consequences for nearly zero energy buildings can be important. Although one has to realise that these measurement are 30 years old and the facades, window frames and wall connections are improved.From measured data in the Netherlands can be concluded that the facade leakage has improved about a factor of 5, see figure 9.

.

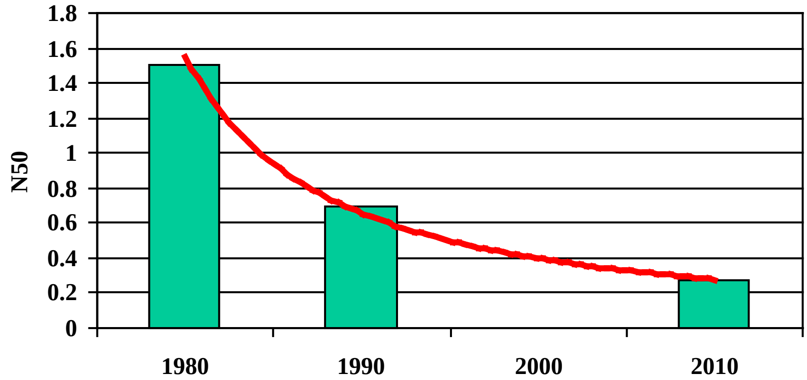

Figure 9. Leakage improvement of facades during the last 3 decades

Nevertheless the relative contribution of facades to the whole house leakage has increased.(see figure 10).

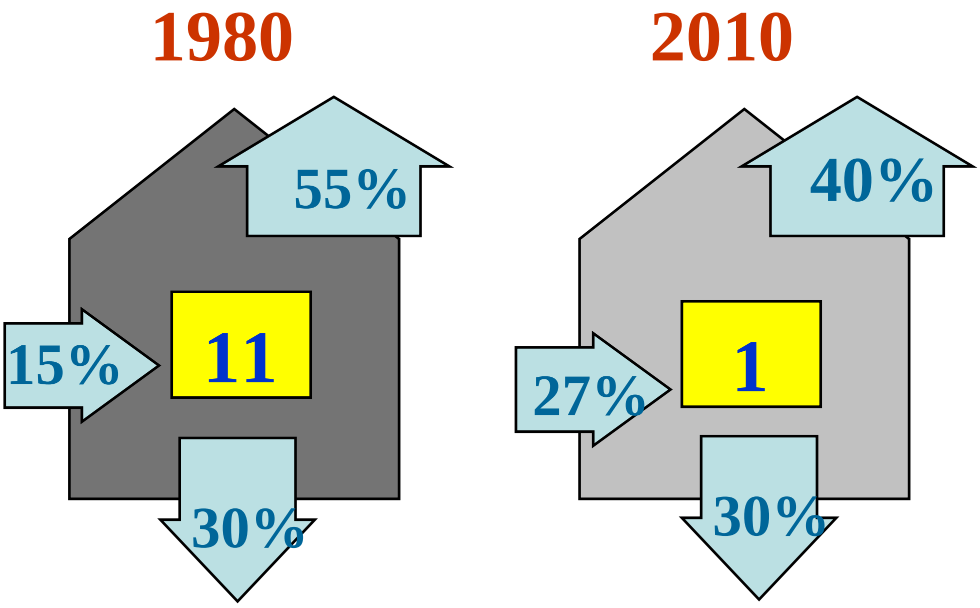

Figure 10. Leakage improvement during 3 decades of whole house with relative distribution

The figure in the middle is the overall N_{50} value for the whole dwelling. In 2010 the leakage of the façade was about 27% of the total leakage against 15 % in 1980.

For the energy balance of nearly zero energy houses infiltration will become relatively more important.
Thus in case the data of this study might be used also nowadays, the time in the year we are measuring the air tightness of buildings might be very important.
In fact it is impossible with a single measurement to do a correct judgement for the air tighness.

Three measurements in subsequent seasons are at least neccesary to judge the air tightness well. This multiple measurements become more important in case a (financial) penalty can be given for not fulfilling the local requirements.

CONCLUSION

The data of this study suggest that one must be very careful with measured air tightness levels. Seasonal effects might change the measured result in the order up to even 100%. Especially for nearly zero energy buildings this can be very important.
The measuremnent accuracy and the resulting uncertainty in the final result may also hinder a right decision in judging air tightness measurement in practice.

ACKNOWLEDGEMENTS

We acknowledge our colleagues Bas Knoll for the excellent detailed report written in 1981 so that we could use the data even 30 years later and Hans Phaff for scanning the report in PDF so that we could use old figures easily.

REFERENCES

[1] Knoll, B. and de Gids, W.F. *Air tightness of 21 window frames in walls during three seasons (in Dutch)*
IMG- TNO, Delft,
report C490, November 1981

ASSESSMENT OF THE DURABILITY OF AIRTIGHTNESS AND IMPACT ON THE CONCEPTION OF BUILDING DETAILS

B. Michaux[1*], X. Loncour[1], C. Mees[1]

1 Belgian Building Research Institute
Av. Pierre Holoffe, 21
1342 Limelette - Belgium
**Corresponding author: bmi@bbri.be*

ABSTRACT

To obtain a good building airtightness is crucial in the context of energy efficient buildings. The building airtightness can easily be assessed at the end of the construction phase by performing a building pressurisation test. Most building regulations include this initial performance and consider it as only criterion. The changes in airtightness during the evolution of the building are not considered. Several elements influence the durability of this building airtightness e.g. as the application of the right products, assembling technologies, unfavourable building environment (dust,…) …. Among those design and implementation factors, the airtightness layer could particularly suffer from moisture, pressure variation and other solicitation occurring during the lifespan of constructions. These different elements are studied in the context of the DREAM research project led by BBRI.

KEYWORDS
Building airtightness, durability, building details, laboratory test, pressurisation test

INTRODUCTION

Nowadays, there is a clear tendency to build more and more to high energy efficiency standards. The European directive on energy performance of buildings [1] states for instance that by the end of 2020 all new construction in Europe will have to be nearly zero energy buildings. In this context, the building airtightness is an important factor as this building characteristic can have a considerable influence on the energy balance. For example, in Belgium, with the energy performance requirements effective in 2012, the level of airtightness can influence the energy performance with about 10 to 20%. The more strict these energy performance requirements are, the more important building airtightness is.

The airtightness level can easily be measured at the end of the construction work by realizing a pressurisation test which is common practice nowadays [2], even in large buildings. When a high airtightness performance level is required, it is even recommended to measure at different stages during the construction phase. Measurements are in particular relevant while the building airtightness layer is still accessible and possible air leaks could be sealed (see Figure 1).

Figure 1. Air leakage detected in the construction phase where improvement is still possible

Most building energy regulations only consider the initial performance of the airtightness, just measured at the end of the construction phase [3]. It is clear that this initial performance can change over time due to several reasons as e.g.

- Changes made at the interior of the building. Some works as painting works could have positive influence, while other works as the placement of wood burning ovens can negatively influence the airtightness,
- Mechanical and hygrothermic loads (and cycles) on the airtightness screen and on all assemblage… (see Figure 2)
- Intervention of the occupant e.g. by boreholes in the building envelope.
- …

Figure 2. Example of inappropriate choice and placement of a sealing kit resulting in a non-durable airtightness performance

In general, there is rarely information available on the durable character of the airtightness at the product level as well as at the component (kit) level, the building detail level or at the whole building level. As investments on the building envelope are meant for the long term, it is essential to pay attention to the durability aspect of the airtightness.

AIRTIGHTNESS OF PRODCUTS

Initial performance

The first step to get an insight into the durability aspect of the airtightness is to obtain information on the initial performance of the products. Most construction products are not perfectly airtight. This is for instance shown in Figure 3 where air leakage through concrete and brick walls is visualized during a pressurisation test in laboratory where a soap/water solution is applied on the walls. The numerical characterisation of the airtighness is reinforced by visual analyse to identify product and combination performances. On the considered type of wall the main leaks appear on the level of the building block itself in the case of concrete wall or at the joints for the brick wall.

Figure 3. Visualization of air leakage by means of a soap/water solution during the determination of the air permeability of a concrete wall

Quantitative information on examples of air permeability testing can be found in the literature (e.g. [4]). This information is always limited to specific test cases. The variablity within a group of similar products can be very large in some cases. For example, tests realized by BBRI show that the air permeability of external walls can vary from a factor 1 to 600, depending on the finishing system used. The type of block also influences the final results.

Wall type	Flow at 50 Pa ($m^3/h/m^2$)	Ratio with reference
Reference : concrete blocs A + all joints filled + 1 cm plastering	0.008-0.023	1
2: concrete blocs B + all joints filled + 1cm plastering	0.028 - 0.047	2
3: concrete blocs A + vert joint opened + 1 cm plaster	0.029 - 0.041	2
4: concrete blocs A + all joints filled + 0.8 cm plaster	0.13 - 0.18	7
5: bricks (terra cotta) + all joints filled + second phase joint on both sides	0.41 - 0.52	20
6: concrete blocs A + all joints filled + paint2 layers (acrylic)	3.01 - 3.11	140
7: concrete blocs A + all joints filled + second phase joints	8.51 - 9.5	400
8: concrete blocs A + all joints filled + second phase joint b	11.58 - 15.0	600

Table 1. Air permeability of various wall types.

Other studies of recent date realized in Belgium have shown significant differences between the results when testing the airtightness of products as OSB board [5]. This performance is most of the time not guaranteed by the manufacturers. Differences in performance by a factor 10 can be observed between panes from different manufacturers. Measurements in practice show variations in Ka values between = 0.01 m³/ h m³ Pa and 0.001 m³/hm²Pa for the most airtight panes. This can be a huge problem in buildings, designed to obtain performant airtightness levels as in passive houses where these OSB panels need to guarantee the airtightness (see Figure 4).

Figure 4. Example of construction where the airtightness layer consists of OSB board

For some products as thin plasterwork commonly applied on cellular concrete or for most types of painting, information on the initial air permeability performance is simply not available and neither is information on the durabilty of this performance.

HOW TO DESIGN AIRTIGHT BUILDING DETAILS BY TAKING THE DURABILTY ASPECT INTO ACCOUNT

Continuity of the airtightness layer

The first step to guarantee airtightness is to clearly identify for each building wall which layer gurantee the airtightness. The interior plastering in case of cavity walls or the vapour barrier on the warm side of the pitched roof fulfill this role.
At the building detail level, the second step is to guarantee a continuity of these airtight layers in all directions (see example on Figure 5). To achieve this continuity, appropriate products e.g. via tapes or other kind of products need to be chosen.

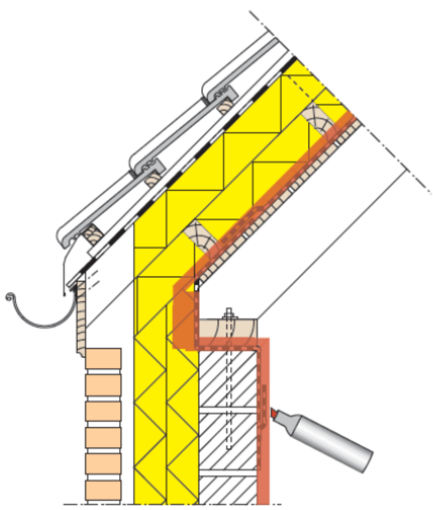

Figure 5. Conception of a building detail in order to guarantee the continuity of the building airtightness layer [3]

Taking into account the durabilty aspect of the airtightness in the design of building details

Quantifying air leackage of building details in laboratory is a first step to get insight into air leakage in practice. This approach shows, however, there are important limitation because of the impossibility to test all the details and their variants , because laboratory conditions to build the mock-ups are quite different from the real building conditions or because the solicitations taken into account while testing performance of the details can differ from the solicitations encountered in real buildings. It is therefore useful to define criterias allowing an assessment of the airtightness durability potential of a detail. This assessement should be possible during the design phase. Criteria can be evaluated in a checklist. A try-out that will be elaborated during the DREAM project is given hereunder.

Following elements could be considered:

- What is the intrensic durability of the products used to guarantee the airtightness? This durability has to be assessed by taking into account the installation conditions. For instance, can the durable character of airtightness of PU-foams be guaranteed ?
- According to the position of the airtightness layer, which type of solicitations can be expected on this layer? The following effects should be taken into account : temperature, humidity, UV, possible construction settlements, pressure differences e.g. due to the wind… The solicitaion of the plasterlayer of a wall cannot be compared with the solicitations of a vapour barrier foil installed in a pitched roof.
- Is the airtightness layer still accessible at the end of the contruction or is this layer hidden and can it not be improved or repaired afterwards? Higher levels of the durability criteria should be set out if the layer is no more accessible at the end of the construction phase.
- The products are te be used for the right purpose. Some products as most tapes are designed to guarantee the airtightness but are not supposed to undergo to regular mechanical solicitations. Construction details should be designed in order to minimise such mechanical solicitations.

Practical questions as e.g. the direction of placement vapour barrier foil inside pitched roof needs to be solved. Mechanical fixation in addition of the tapes will have a positive influence on the durability of the airtightness system. Tapes are in this case only used to guarantee the airtightness. In this way, they are not submitted to mechanical solicitation e.g. due to wind pressure differences.

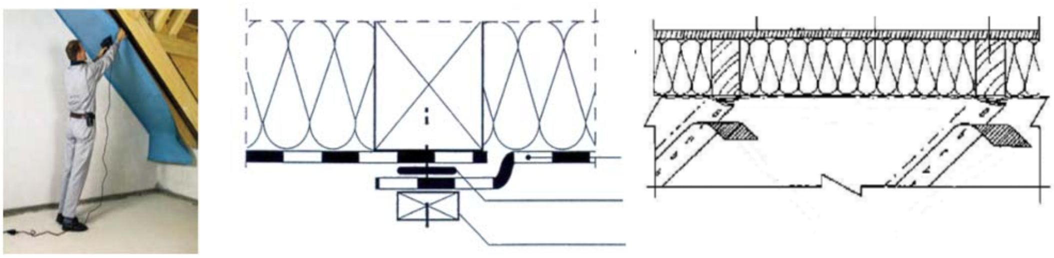

Figure 6. Example of mechanical fixation of the vapour barrier system within a pitched roof. This solution avoids mechanical solicitation of the tapes.

THE DREAM PROJECT

The DREAM research project supported by the Walloon Region in Belgium aims to assess the initial performance and the durability of the airtightness of building products such as complete walls and junctions, or connections with a pitched roof. The research is based on laboratory tests that are carried out between early 2012 and late 2013. One of the objectives of this project is to define a set of general design rules allowing to improve the durability of the airtightness for construction details.

Accelerated ageing tests will be applied on the products and building details in order to get an insight into the durability of the airtightness performances. The impact of wind pressure cycles, variation of temperature, variation of humidity, exposure to UV and possible building settlements will be examined on a set of 50 building details. Wind pressure cycles will show which performance will remain unaffected in a pitched roof after the equivalent of 10 years, 20 years. The impact of storm will also be taken into account.

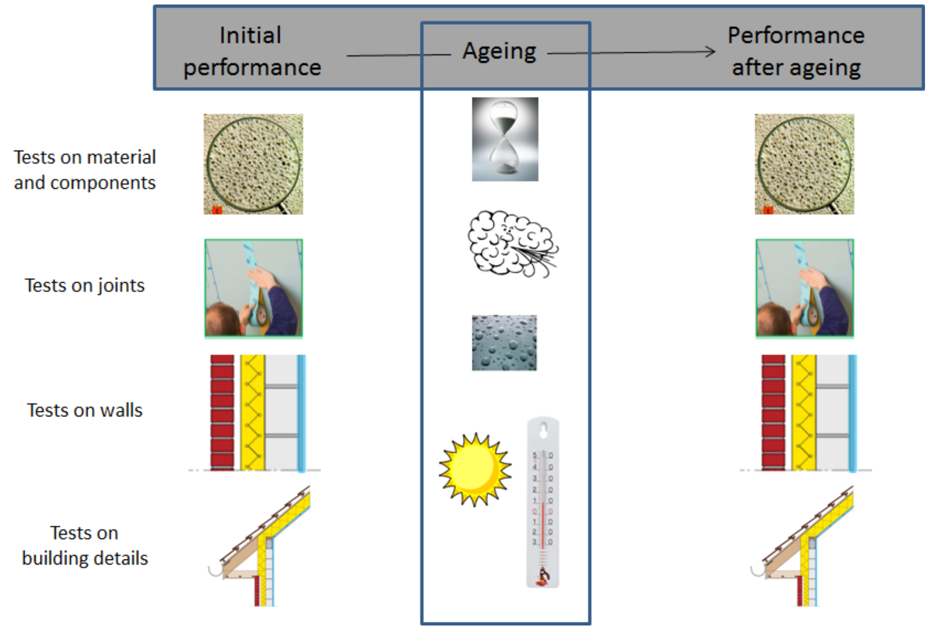

Figure 7. View of the different types of tests realized in the DREAM project

CONCLUSION

Energy savings in buildings require paying attention to the airtightness, conception as well as building details. Nowadays, only the initial performance of airtightness measured during the pressurization test made at the end of the construction phase is taken into account. Important questions on the durability aspect of this airtightness remain unanswered. Simple principles can be applied at the level of building detail in order to increase this durability. These principles are studied in the scope of the Belgian DREAM project.

ACKNOWLEDGEMENTS

The DREAM project realized by BBRI in collaboration with the University of Liège (ULG) is financially supported by the Walloon Region in Belgium.

REFERENCES

[1] Directive 2010/31/EU of the European Parliament and of the council of 19 May 2010 on the energy performance of buildings (recast)

[2] NBN EN 13829 *Thermal performance of buildings – Determination of air permeability of buildings – Fan pressurization method* (ISO 9972:1996, modified). Brussel, NBN, 2001.

[3] Aurlien, T. Rosenthal, B. *International comparison of envelope airtightness requirements & success stories that could inspire the EC and other MS*, Stimulating increased energy efficiency and better building ventilation, March 2010, INIVE, 321-326

[4] Orme, M. Liddament, M. Numerical data for air infiltration & natural ventilation calculations – AIVC TN44 – 1994 - ISBN 1 946075 97 2

[5] Langmans, J. Klein, R. Roels, S. *Air Permeability Requirements for Air Barrier Materials in Passive Houses*. In International Symposium on Building and Ductwork Air-tightness .Copenhagen : 2010

[6] CSTC contact 2012-1 – *Etanchéité à l'air*, BBRI – www.bbri.be

[7] Langmans J., Hoe luchtdicht is OSB nu eigenlijk? 10 jaar ISOPROC, 28/10/2011

Reasons behind the new approach to requirements in the energy performance regulation RT 2012

Jean-Christophe Visier, CSTB, France

CAN WE LEARN FROM THE SWEDISH QUALITY APPROACH TO DUCTWORK AIRTIGHTNESS AND THE REGULAR INSPECTION OF VENTILATION SYSTEMS?

Johnny Andersson

Technical Director
Ramboll
P.O.Box 17009
SE-104 62 Stockholm, Sweden

ABSTRACT

Practically all buildings and their installations in Sweden are performed according to the quality requirements in AMA specification guidelines (General Material and Workmanship Specifications). The AMA requirements are made valid when they are referred to in the contract between the owner and the contractor.

The need for tight ventilation ductwork systems has been identified in Sweden since the early sixties. Sweden has thus a long and unbroken tradition of demanding and controlling the tightness of ventilation ductwork as specified in the HVAC-part of AMA. During this long period, since 1966, we have raised the tightness requirements in tact with technology improvements (to a great extent influenced by the AMA requirements) and increased energy costs. As shown in two EU-projects this long time focus on ductwork quality in Sweden has resulted in very low air leakage in normal Swedish duct installations.

Many studies in Sweden and other countries identified during the 1980’s defective ventilation systems and insufficient airflows as a main reason for occurrence of sick buildings and health problems not least for children in schools and day nurseries. A large Swedish allergy study reported an increase of different types of allergy reactions parallel with other nationwide studies reporting inferior ventilation in many dwellings and premises.

Consequently, 1971 a compulsory system for ventilation control (OVK) started in Sweden with aim to control and improve the function of ventilation installations. According to the ordinance (1991:1273) a control of the ventilation in most types of buildings has to be made before the installations are taken in to operation and then regularly at recurrent inspections.

AMA – A SIXTY YEAR OLD SYSTEM FOR SPECIFYING QUALITY

AMA (General Material and Workmanship Specifications) is a Swedish voluntary complementary to statutory rules, regulations and specified building standards laid down by the authorities. The statutory rules are normally mostly focussed on reducing the risk of injuries while AMA (not having to deal with that) is focussed on reducing damages and LCC-costs. Common interest areas for both are sustainability and low energy use.

AMA is thus a tool for the future proprietor (and his consultant) to specify the requirements for a new project – it could e.g. be buildings, installations, roads, and tunnels. AMA thus covers all aspects of building and installation works and is split up in parallel main parts from foundation to HVAC and electrical installations. Each of the AMA books (covering the requirements) are accompanied by a parallel book (e.g. “RA – Advices and Instructions”) comprising advices on how to specify and quantify systems and components. The AMA books are shown in Fig. 1.

AMA follows the project through all phases: from the *design phase* (advices to the designer), to *tender* documents with specifications (references to relevant AMA clauses and advices on how to quantify), to *installation* (quality requirement e.g. for duct connections, insulation of ducts or soldering of copper pipes), *testing* (e.g. measurement methods, protocols, e.g. for tightness test of ductwork), and *maintenance* (e.g. labelling and marking of components, cleaning of ductwork).

Figure 1. The AMA family (VVS = HVAC), 1998 edition.

AMA – an easy and accepted tool

The AMA requirements are made valid when they are referred to in the project contract between the owner and the contractor. A common AMA-rule states that these requirements shall be expressed in measurable terms combined with control methods with known (and possible low) measurement errors. Another AMA-rule is that the cost for fulfilling the demands shall be calculable for the tenderers.

The level of the AMA quality requirements are based on a kind of “80/20”-type rule. They should be suitable for most of the applications (“80 %”) while for the rest they are either too high (the project, e.g. a building, has a very short planned life span and thus does not need the normal AMA quality) or too low (for projects where a higher quality is needed, e.g. laboratories and hospitals).

The AMA quality requirements are lifted when possible by technology progress and when found profitable for the owner on a Life Cycle Cost basis. Proposed increased requirements are established after they have been referred for consideration to a large number of owners, manufacturers, contractors, consultants and other interested parties. Wherever possible, AMA refers to relevant national Swedish standards and European norms. Twice a year the AMA requirements can be updated through the AMA-nytt (AMA News) Journal and added to computer-based specification tool used by the consultants. AMA is published by The Swedish Building Centre, a non-profit organization).

Long History of Ductwork Requirements in Sweden

In Sweden requirements on ductwork tightness have been specified as part of building specifications since the AMA edition 1966.

As described the AMA quality requirements are raised when possible by technology progress and when found profitable for the owner on a Life Cycle Cost basis. This is also true for ductwork tightness requirements:

<u>AMA version 1966</u>:
Two “tightness norms” A and B, were defined. They were to be spot checked by the contractor; minimum tested duct surface area was 10 m²;

<u>AMA version 1972</u>:
Requirements were transformed into two “tightness classes” A and B (same as the EUROVENT classes today). Class A was the basic requirement for the complete duct system in the air handling installation (i.e. including dampers, filters, humidifiers and heat exchangers). It was advised to raise the requirement to meet Class B when:

- The system operates for more than 8 hours/day
- The air is treated (cooling, humidification, high class filters etc.).

<u>AMA version 1983</u>:
In this version of AMA, tightness Class C is added. The following requirements are given:
Class C for round ductwork larger than 50 m²
Class B for round duct systems with a surface area smaller than 50 m² and also for rectangular ductwork
Class A for visible supply and exhaust ducts within the ventilated room;

<u>AMA version 1998</u>:

In this version of AMA, a tightness Class D has been added (i.e. 3 times tighter than Class C). The use is not specified. It is an optional requirement for larger circular duct systems and where leakage can lead to hazards.

<u>AMA version 2007</u>:
Now also rectangular ductwork has to meet tightness class C.

Often the duct manufacturers initially objected to the increased demands but as soon as one of them quickly announced that e.g.: “We can meet the new AMA requirements”, the rest of the gang was forced to follow.

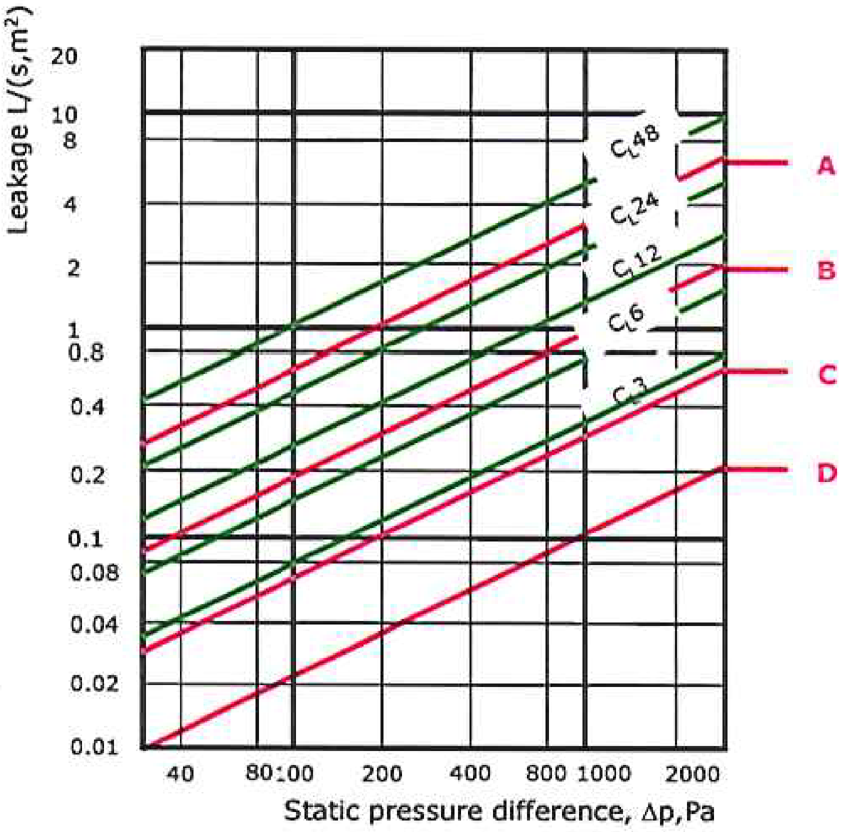

Figure 2. Eurovent Tightness Classes A – D and ASHRAE Classes C_L 48 - 3.

Require and control!

In Sweden a ductwork system is not specified to be tight – instead the permissible leakage rate at a specified test pressure is stated – that is possible to measure!
And if this is not fulfilled when checked, the contractor has to redo his job until found OK!

Thus two of the AMA rules are relevant for ductwork tightness: “Express your requirements in measurable terms and control that you have got it!” and the other: “The costs and risks for the contractor to fulfil the requirements in the contract should be possible to calculate”.

Unless otherwise specified the tightness classes are to be in accordance with AMA demands (as stated above). AMA also states the requirements for the testing of ductwork tightness.

The duct system leakage has to be verified; normally by the contractor as part of the contract (i.e. the cost for this first test is normally included in the contract lump sum). This test is undertaken as a spot check where the parts to be checked are chosen by the owner's consultant. For round duct systems 10 % and for rectangular ducts 20 % of the total duct surface normally has to be verified.

In case the system is then found to be leakier than required, that part of the tested system shall be tightened and another equally sized part of the system shall be verified in the same manner. Should this part also be found to leak more than accepted the complete duct installation has to be leak tested and tightened until the requirements are fulfilled.

The costs for the tests – the first 10 %, then another 10 % if not accepted and then at the end the whole system - is part of the contract, i.e. covered by the contractor. The mechanical contractor can either make the tightness test with his own personnel, provided he has equipment and skilled personnel to do that, or he can have it done by another specialized contractor. In both cases he has to cover the costs which can be quite considerable if the tests have to be repeated due to bad test results. The result of the leakage test shall be reported on AMA standard protocols and handed over to the owner.

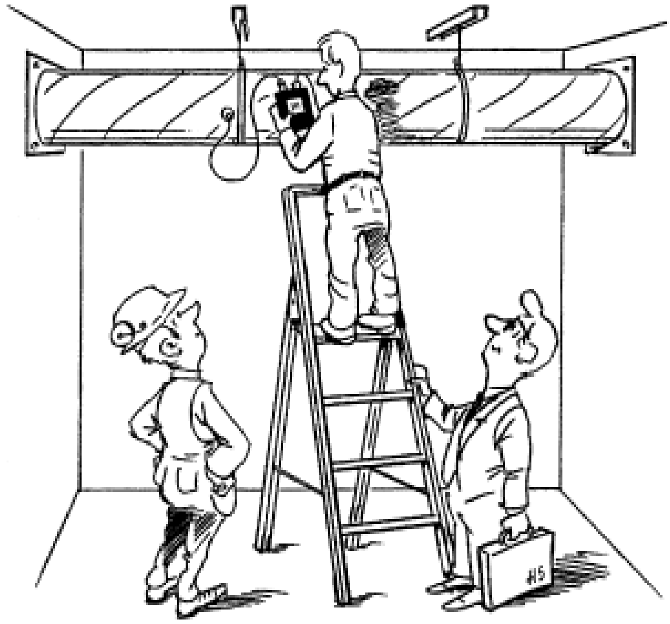

Figure 3. Express your demands in measurable units and measure it!

This method of working is one factor that has led to high quality ductwork standard in Sweden. The contractors do their best to avoid costly setbacks from inferior duct quality. The duct manufacturers are competing in inventing and marketing tight duct systems that are easy to install. Both circular and rectangular duct connections are provided with rubber gaskets that are very tight compared to older (and foreign) systems. New types of duct joints have reduced earlier laborious installation works.

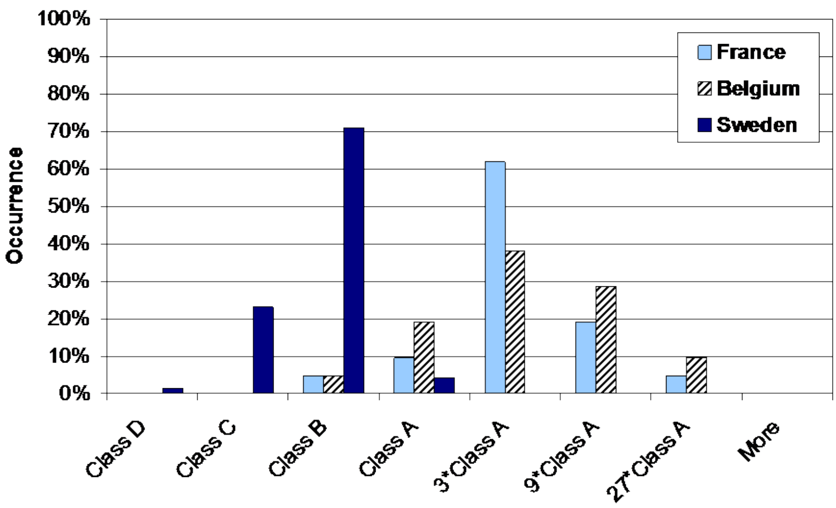

Figure 4. Comparison of the results from an EU project – Ductwork in Sweden was 25-50 times tighter!

The Swedish experience could be an interesting concept for other countries

Duct leakage is detrimental to energy efficiency, comfort effectiveness, indoor air quality, and sometimes even to health. However, in most countries designers, installers, building managers and building owners, often ignore the benefits of airtight duct systems. Furthermore, as there are no incentives in most countries, over the years, this has (probably) lead to poor ductwork installations in a large fraction of the building stock.

In these countries, installation is (probably) often undertaken using conventional in situ sealing techniques (e.g. tape or mastic), and therefore the ductwork airtightness is very much dependent upon the workers' skills..

The measurements and literature review performed within the EU-project SAVE-DUCT found that duct systems in Belgium and in France are typically 3 times leakier than EUROVENT Class A, see Figure 4. Typical duct systems in Sweden fulfilled the requirements for EUROVENT Class B and C and were thus between 25 – 50 times tighter than those in Belgium and France.

The answer to the question "Why this large difference between the countries?" is most probably that Sweden has required tight ducts, i.e. specifying how much they are allowed to leak at a certain test pressure, since the early sixties whereas in the two other countries tightness of ductwork is normally neither required nor tested.

OVK - A SWEDISH COMPULSORY SYSTEM FOR VENTILATION CONTROL

Inferior ventilation a common cause for sick buildings

Many studies in Sweden and other countries identified during the 1980's defective ventilation systems and insufficient airflows as a main reason for occurrence of sick buildings and health problems not least for children in schools and day nurseries. A large Swedish allergy study reported an increase of different types of allergy reactions parallel with other nationwide studies reporting inferior ventilation in many dwellings and premises.

The first **Healthy Buildings**-conference was held in Stockholm 1988 and here bad functioning ventilation was found to be a common cause for allergies and other hazards indoors. In one of the sessions it was defined that: "Dilution is not the only solution to pollution". Emissions from building materials, furniture, detergents and many other sources resulted in high indoor pollution levels as the necessary diluting ventilation air flows did not exist.

In Sweden BFR, The Council for Building Research financed many Nordic air quality research studies; one of the largest was "The Healthy Building" were inferior ventilation once more came into focus. Many studies showed that ventilation systems were badly maintained – filters were e.g. not changed when needed resulting in too low air flows.

A new ordinance requiring ventilation control

Consequently, 1971 a compulsory system for ventilation control (OVK) started in Sweden with aim to control and improve the function of ventilation installations. According to the ordinance (1991:1273) a control of the ventilation in most types of buildings has to be made before the installations are taken in to operation and then regularly at recurrent inspections.

Depending on the type and use of the building and the type of ventilation system the following inspection intervals are stipulated:

• Day nurseries, schools and hospitals	3 years
• Block of flats, office with FT-ventilation	3 years
• Block of flats, office with F-ventilation	6 years
• Block of flats, office with S-ventilation	6 years
• One- two dwelling-houses with FT-ventilation	only first inspection (new buildings).

FT = Supply and extract: F = Extract; S = natural ventilation

OVK inspectors

OVK inspectors shall have a relevant education and experience and be suitable for the task. The authorization is time-limited and may also be limited to certain types of ventilation systems. It is the building's owner who is responsible for carrying through the OVK inspection and who is also appointing the inspector.

Notes shall be taken and the result of the OVK inspection shall be reported on a special protocol. The owner of the building shall as soon as possible rectify fault s and defects found at the inspection.

The municipal commission responsible for questions relating to planning and building law, normally the local housing committee, is responsible for monitoring that the building owners fulfill their duties. This responsibility is facilitated by one of the inspection protocol copies are sent to the municipality. Approved OVK inspectors can be certified for different applications:

- E – simple systems, corresponding to apartment units in blocks of flats
- S – natural ventilation systems for system for blocks of flats and office buildings
- N – normal, this is valid for E, S and FT-systems for small houses
- K – complicated, this is valid for all types of ventilation systems.

Furthermore these inspector categories are split up in nation-wide and local authorizations.
Those with nation-wide authorizations shall fulfill certification requirements according to regulation from The National Board of Housing, Building and Planning.

OVK inspections

The first inspection shall comprise the following elements:

- That the function and the quality of the ventilation system correspond to valid directions
- that the system does not contain pollutants that can be spread in the building
- that instructions and maintenance manuals are easy available for the maintenance personnel
- that the system moreover functions in the way that was intended (designed).

Recurrent inspections shall control that the function and quality of the ventilation system corresponds to the directions valid at the time the system was taken into operation and also that the last three items above are fulfilled.

Supervision of the OVK examination results

The municipality is the local supervising authority and is responsible for the supervision of OVK. They shall keep a register of the OVK protocols, control that the inspections are made, and control that the building owners take care of the reported deficiencies.
Furthermore the municipalities themselves are often owners of many of the building that have a high inspection priority, e.g. day nurseries, schools and care institutions.

According to the Swedish national environmental legislation in the year 2020 all buildings shall be healthy and have a good indoor environment. One of the intermediate goals within the frame of good indoor climate is that: “all buildings where people stay often or during a longer time shall 2015 at the latest have been proven to have a functioning ventilation system.

CONCLUSION

Back to the opening question:
Can we learn from the Swedish quality approach to ductwork airtightness and the regular inspection of ventilation systems?

Yes, I think so but you are the best judges!

REFERENCES

ASHRAE. 2012. ASHRAE handbook—Fundamentals, Chapter 34 Duct Design. Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

Carrié FR, Andersson J, Wouters P. 1999. Improving ductwork. A time for tighter air distribution systems. AIVC, Air Infiltration and Ventilation Centre.

Malmstrom T, Andersson J, Carrié FR, Wouters P, Delmotte Ch. 2002. AIRWAYS Source book on efficient air duct systems in Europe. Belgian Building Research Institute.

VVS AMA 98. Allmän material- och arbetsbeskrivning för VVS-tekniska arbeten. AB Svensk Byggtjänst. Stockholm 1998. Copyright 1998.

VVS&Kyl AMA 07. Allmän material- och arbetsbeskrivning för VVS-tekniska arbeten. AB Svensk Byggtjänst. Stockholm 1998. Copyright 2007.

Ordinance (1991:1273) of Function Control of Ventilation Systems (OVK)

The National Board of Housing, Building and Planning, Directions of Function Control of Ventilation Systems (OVK) BFS 2012:6..

KEYWORDS

AMA, Ductwork, Tightness, OVK, Function Control of Ventilation Systems

UK EXPERIENCE WITH QUALITY APPROACHES FOR AIRTIGHT CONSTRUCTIONS

Martin Liddament

VEETECH Ltd
7a Barclays Venture Centre
Sir William Lyons Road
Coventry
UK
CV4 7EZ

ABSTRACT

In the past much of the UK building stock has had a relatively high permeability and relied on this natural porosity to meet the bulk of winter ventilation needs. Lack of control, however, has resulted in unnecessarily high energy consumption. Therefore, in order to meet energy efficiency and carbon emission targets, airtightness requirements have been incorporated in the British Building Regulations. Quality is essentially enforced through the Building Regulations which, for the majority of new buildings, require full pressure testing on meaningful samples of buildings in each development. In addition, this testing is required for almost all building types including dwellings and non-residential buildings. Quality of airtightness performance is achieved through compliance requirements including the certification of testers, the calibration of equipment and detailed definition of the testing and reporting procedures. Because increased building airtightness is a relatively new requirement (with strong enforcement not occurring until after 2006) there is still a dearth of operational data. Therefore current results are limited. However available results indicate that builders are usually able to meet requirements with respect to airtightness. Durability issues still need to be addressed with one test showing that permeability increased for two thirds of buildings that were re-tested between one and three years after construction. On the other hand some buildings showed increased airtightness on re-testing. An understanding about airtightness among building occupants has proved to be problematic with surveys showing that many occupants perceive airtightness in a negative way. In the dwelling sector, airtightness has been increasingly introduced in conjunction with the use of mechanical ventilation heat recovery (MVHR) systems. This has particularly applied to the low income housing association sector. Current studies show that the implementation of energy efficient mechanical ventilation systems, in conjunction with airtightness, requires improvement. Examples of successful MVHR performance in terms of energy effectiveness and performance reliability are not yet well documented.

KEYWORDS

Compliance requirements, durability of airtightness, field measurements, occupant reactions, interaction with ventilation.

INTRODUCTION

Traditionally, the UK building stock has been naturally ventilated and, frequently, the natural permeability of the building has been relied upon to provide much of the ‘background’ ventilation need, especially during the winter. However, poor airtightness in buildings has become a particular concern because the associated uncontrolled air infiltration seriously impacts on efforts to reduce energy consumption. Thus airtightness regulations have been introduced and hence reliance on air infiltration is no longer seen as viable. Ventilation performance regulations are covered in Part F of the British Building Regulations [1] while airtightness and energy efficiency requirements are contained in Part L of the Building

Regulations [2][3]. In the Regulations, factors such as the energy and heat recovery performance of systems are taken into account. This has resulted in increasing pressure on combining airtightness with the use of mechanical systems with heat recovery (MVHR), especially in dwellings. As a consequence the implementation and quality of airtightness has become linked to MVHR performance, energy efficiency, indoor air quality and component durability. In the British Code for Sustainable Homes [4] the highest energy efficiency specifications invariably require MVHR. These specifications particularly apply to low income housing association homes and therefore it is important that quality approaches towards airtightness and ventilation are robust and largely maintenance free.

This paper attempts to review these issues in relation to published information on the performance of airtightness and its impact on energy, ventilation performance, air quality and user perception. Because increased building airtightness is a relatively new requirement (with strong enforcement not occurring until after 2006) there is still a dearth of data. Therefore current results are limited. In many cases, available results indicate lack of knowledge among building users about how to benefit from and adapt to airtightness. For similar reasons successful performance, in relation to energy efficiency is not yet well documented.

THE UK QUALITY MANAGEMENT APPROACH

Quality management begins with the legislative requirements for airtightness which is implemented through a series of compliance and testing methods. At all stages testing and monitoring is undertaken according to approved accreditation schemes. This strongly motivates both design and site practice because any failure results in expensive retesting, re-design and remedial work. In practice it has been shown that builders are generally able to fulfil current airtightness requirements. A summary of the UK quality management approach is presented in Table 1 and described in further detail below.

Requirement	Action
Legislation	Buildings must comply with air permeability requirements (Building Regulations Part L)
Building Types	Dwellings and non-residential
Compliance	Through on-site measurements and remedial action (covers most buildings).
Certification of Testing Organisations and Individuals	Must be certified by the British Institute of Non-destructive Testing (BINDT) through the Airtightness Testing Association (ATA)
Equipment Validation	Equipment must be calibrated by organisations certified to undertake such validation by the UK Accreditation Service (UKAS)
Testing and Reporting Procedure	The testing and reporting procedure must conform to the requirements of the Airtightness Testing and Measurement Association (ATTMA). The testing regime is agreed with and monitored by the Local Authority Building Control Manager (BCM).

Table 1. The UK Quality Management approach for building airtightness.

Legislation

Regulations for airtightness are covered in detail in the related paper 'Philosophy and Approaches for Airtightness Requirements in the UK' [5]. In summary, airtightness is specified in terms of 'air permeability' at an induced pressure of 50 Pa. The current maximum air permeability permitted by the UK Building Regulations for most buildings is 10 $m^3/(h.m^2)$ at 50 Pa with proposals currently under discussion that it should be reduced to 3 $m^3/(h.m^2)$ at 50 Pa for air conditioned buildings and 5 $m^3/(h.m^2)$ at 50 Pa for other types of building by 2016 [6]. In practice a much tighter specification than given by the maximum air permeability may be needed in order to meet the overall energy and carbon dioxide emission targets for the building.

Building Types

Airtightness requirements apply to virtually all building types (i.e. dwellings and non-residential buildings).

Compliance

Airtightness compliance is primarily verified through a whole building pressurisation test. Small commercial buildings of less than 500 m^2 of floor area and housing developments of no more than two dwellings can be exempted from testing. However, in these instances, the assumed air permeability, for compliance with energy efficiency targets, is taken as 15 $m^3/(h.m^2)$ at 50 Pa. Large and complex buildings may also be evaluated without whole building pressurisation but strict conditions apply as summarised in [5]. If satisfactory performance is not achieved remedial measures must be carried out and the building retested until the building does not exceed the required permeability. In addition, if the development incorporates buildings of similar design, then an additional building must be selected for testing. Any remedial measures must also be applied to the remaining similar buildings.

The delay and cost of undertaking remedial work and retesting provides a strong incentive to ensure the initial quality of design and construction.

Certification of Testing Organisations and Individuals

Quality is further secured by requiring that testing organisations and individual testers must be certified by the British Institute of Non-destructive Testing (BINDT) through the Airtightness Testing Association (ATA) [7]. Testers must be specifically certified according the type of building to be tested. Gaining a certificate of competence is achieved through undertaking a training approved by the ATA.

Equipment Validation

Pressure testing and associated equipment must be calibrated by organisations certified to undertake such validation by the UK Accreditation Service (UKAS). All equipment must have been calibrated within at least 12 months prior to conducting a test.

Testing Method and Reporting Procedure

The approved method of testing and reporting is prescribed by the Airtightness Testing and Measurement Association. Full testing and reporting requirements can be downloaded from:

- Dwellings: [8]
- Non-residential buildings [9]:

Testing may be undertaken on a sample of buildings. In a large housing development the test should be made on at least three units of each dwelling type. In addition, testing should be undertaken within the construction of the first 25% of each dwelling type so that any faults in design can be corrected before the remaining buildings are constructed. These issues are described in more detail in [5]. In practice, and depending on the size of the development, approximately 10 – 20% of buildings on a development will be pressure tested for airtightness. The actual testing regime and amount of testing is agreed with and monitored by the Local Authority Building Control Manager (BCM).

Reporting must follow Section 4 of the ATTMA specification [8][9] and include full details of building dimensions and test results for incremental pressures etc. The results and the data upon which they are based must be given to the relevant Local Authority not later than seven days after the final test is carried out. All results must be reported including those of tests that failed to reach the required level of permeability.

EXPERIENCE OF AIRTIGHTNESS QUALITY

Permeability Database

A database of air permeability measurement results is evolving for dwellings and non-residential buildings. A typical example of air tightness distribution of 1293 dwellings, taken from Leeds Metropolitan University and the NHBC, is illustrated in Figure 1 [10]. This shows that the vast majority meet the current minimum requirement of 10 $m^3/(h.m^2)$ at 50 Pa, with the peak at approximately 6 – 7 $m^3/(h.m^2)$ at 50 Pa. Approximately a third of the measurements are at or below 5 $m^3/(h.m^2)$ at 50 Pa and about 4% are at or below 3 $m^3/(h.m^2)$ at 50 Pa (approximately corresponding to the Swedish 1980 airtightness value for dwellings [11]. A considerable improvement is therefore needed to match projected airtightness requirements for the 2016 Regulations [6].

The current measured variability does impact on ventilation concerns, especially if the space is naturally ventilated. In Part F of the Building Regulations (ventilation requirements) [1], different opening sizes apply for natural ventilation trickle ventilator openings if the air permeability is less than 5 $m^3/(h.m^2)$ at 50 Pa. Therefore it is important that the sizing of natural ventilation openings is consistent with the measured air permeability. In other words, the measured permeability of the building must not be less than the design value unless openings have been sized to match a permeability of less than 5 $m^3/(h.m^2)$ at 50 Pa. In the case of MVHR systems the opposite is most likely to apply. This is because a high degree of airtightness is essential for these systems to work efficiently. In this case, although the measured value is far less significant in terms of meeting ventilation need, in order to satisfy the target energy for the building an air permeability significantly less than the maximum permitted value of 10 $m^3/(h.m^2)$ at 50 Pa will almost certainly be needed.

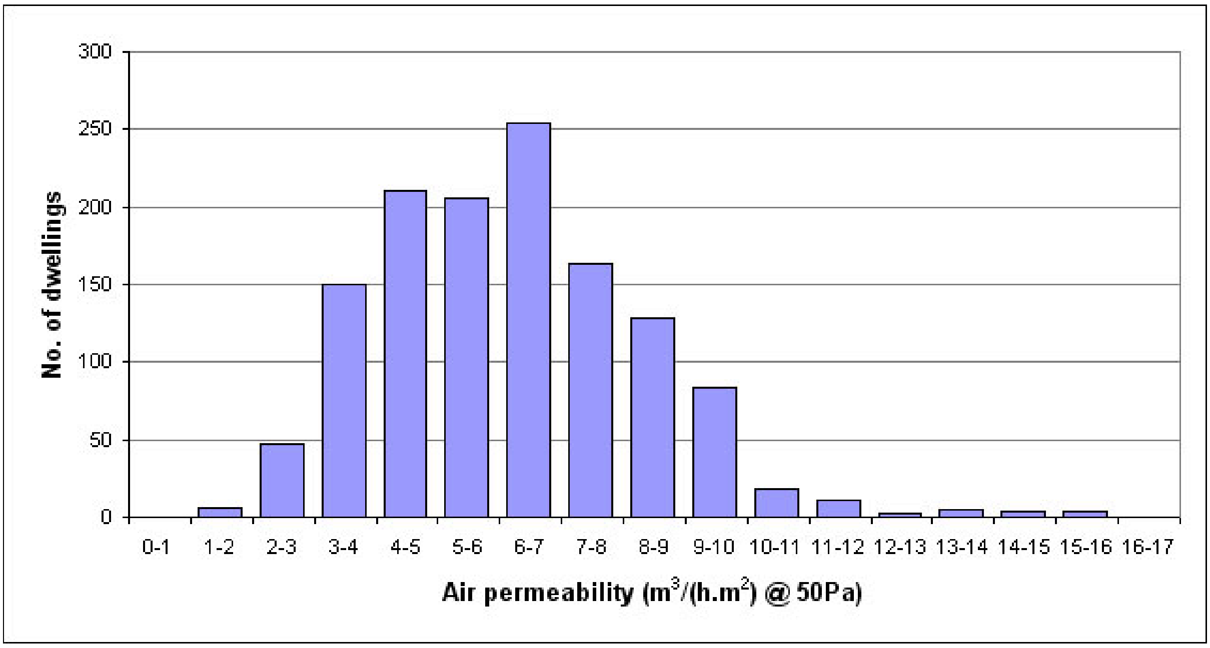

Figure 1. NHBC Air permeability measurements of 1293 dwellings built to 2006 Building Regulations (Figure taken from "Airtightness of UK Housing" Leeds Metropolitan University: http://www.leedsmet.ac.uk/teaching/vsite/low_carbon_housing/airtightness/housing/index.htm).

Increase in Airtightness of New Construction

In recent years the National House Building Council has collated records for many new houses [12]. This has shown that between the years 2007 to 2009 significantly more houses have air permeability values in the range 3 – 5 $m^3/(h.m^2)$ at 50 Pa and fewer are in the range 7 – 10 $m^3/(h.m^2)$ at 50 Pa. Marginally more (approximately 5% are recorded at less than 3 m3/(h.m2) at 50 Pa and very few (approximately < 2% are greater than 10 $m^3/(h.m^2)$ at 50 Pa at 50 Pa. Approximate bands for measurements made in 2009 are:

- > 10 $m^3/(h.m^2)$ at 50 Pa 2 %;
- 7 - 10 $m^3/(h.m^2)$ at 50 Pa 20 %
- 5 – 7 $m^3/(h.m^2)$ at 50 Pa 34 %
- 3 – 5 $m^3/(h.m^2)$ at 50 Pa 38 %
- < 3 $m^3/(h.m^2)$ at 50 Pa 6 %

EXPERIENCE OF DURABILITY OF AIRTIGHTNESS

Currently much of the airtightness effort has focused on testing and compliance at the time of construction. Durability results are limited but research has been undertaken by the NHBC Foundation which has carried out tests on a limited number of houses (23 houses) at intervals of between 1 year and 3 years after construction [12]. The research found that, whilst two-thirds of homes did become leakier, the remaining third actually appeared to become more airtight. It is shown that the type of dwelling, construction, heating and ventilation all have a bearing on the extent to which air permeability changes.
The changes in performance between the original test and the re-test were as follows:

- 15 dwellings (65%) became leakier, on average by 1.5 m3/(h.m2) at 50 Pa although the range of change is wide;

- 8 dwellings (35%) got tighter, on average by 0.63 m3/(h.m2) at 50 Pa.

Only two of the twenty three houses were fitted with MVHR. The changes in airtightness in these buildings were very marginal compared to the naturally ventilated buildings but the sample size was too limited and building varieties too broad to make any inferences.

During the re-tests, the following features on the properties with the most significant leakage were recorded: loft hatches, recessed lighting, around front doors, through window and patio door seals, radiator pipe penetrations, behind kitchen units, around the boxing to soil and vent pipes, and around bath panels and shower trays. Detached houses generally became leakier than apartment buildings

Curiously although the report states that “When tested, one to three years after completion, the air permeability of two thirds of the dwellings tested had increased (i.e. had become leakier)” it goes on to state in the conclusions that: “Evidence from this programme of re-testing of 23 homes up to three years after construction does not support the hypothesis that the air permeability of new homes increases during the first months and years after completion.” The results stress however that the small sample size means that firm conclusions cannot be drawn. However the variations identified by the NHBC Report would indicate that further study is urgently needed.

OCCUPANTS’ EXPERIENCE ABOUT QUALITY AND PERCEPTION OF AIRTIGHTNESS

Doubts have been expressed by some occupants about the concept of airtightness. As an example, in its report ‘Indoor air quality in highly efficient homes’ the Zero Carbon Hub [13] cites a survey by Davis and Harvey [14] in which, when asked about airtightness, the general perception of homeowners was that fresh air is required to maintain the health of a home and its occupants. Airtightness was identified as a source of great concern for homeowners because of fears that increased airtightness may restrict access to fresh air and ventilation. The report states that house builders were relatively optimistic about their ability to build to the required standards of airtightness, but expressed concern about air quality and the welfare of homeowners.

Similar results have also been identified by a recent survey of householders commissioned by the National House Building Council [15]. They report that fewer than half of respondents think that an airtight home sounds like it would be a positive thing until it is described in an alternative way.

The UK Zero Carbon Hub has published a report on Mechanical Ventilation with Heat Recovery in new homes that makes reference to airtightness issues [16]. This makes recommendations for changes needed to ensure, that whilst delivering energy benefits, homes deliver a healthy internal environment.

In Scotland the Sullivan report [17] (see also the related publication [5] stresses the need for occupants of airtight buildings to be prepared to adjust their lifestyle to rely solely on mechanical ventilation with heat recovery (MVHR), including frequent changes of filters and the associated running costs.

From the above it can be seen that mush needs to be done to convince occupants about the importance of airtightness.

CONCLUSIONS

Airtightness requirements and testing have largely been accepted by the industry in the United Kingdom. Measurements in dwellings and commercial buildings now run into thousand per year. There is a well organised testing industry coordinated through the Airtightness Testing and Measurement Association and other certification bodies.

The UK has strong legislative, testing and compliance procedures to ensure that airtightness requirements are met. Data shows that builders are usually able to achieve the required airtightness target.

There is some concern among occupiers about airtightness. Also the reliable performance and durability of associated mechanical ventilation systems, designed to operate in airtight buildings, have yet to be demonstrated.

REFERENCES

[1] UK Government. 2010. *Building Regulations Approved Documents Part F: Ventilation* http://www.planningportal.gov.uk/buildingregulations/approveddocuments/partf/approved

[2] UK Government. 2010. *Building Regulations Approved Document Part L1A: Conservation of Fuel and Power (New Dwellings).* http://www.planningportal.gov.uk/buildingregulations/approveddocuments/partl/approved

[3] UK Government. 2010. *Building Regulations Approved Document Part L1B: Conservation of Fuel and Power (New Buildings other than Dwellings*) http://www.planningportal.gov.uk/buildingregulations/approveddocuments/partl/approved

[4] UK Government. 2010. *Code for sustainable homes technical guide*. www.planningportal.gov.uk/uploads/code_for_sust_homes.pdf

[5] Liddament M. 2012. *Philosophy and Approaches for Airtightness Requirements in the UK*. Workshop Tightvent Europe, March 27th – 28th 2012.

[6] UK Government. 2012. Consultation on changes to the Building Regulations www.communities.gov.uk/.../planningandbuilding/pdf/2077834.pdf

[7] BBINDT 2012 British Building Institute of Non-Destructive Testing

[8] ATTMA. 2010. *Measuring air permeability of building envelopes (dwellings)*. Technical Standard L1. http://www.attma.org/downloads/ATTMA%20TSL1%20Issue%201.pdf

[9] ATTMA. 2010. *Measuring air permeability of building envelopes (non-dwellings)* Technical Standard L2.

[10] Leeds Metropolitan University (2012) *Airtightness of UK Housing* http://www.leedsmet.ac.uk/teaching/vsite/low_carbon_housing/ airtightness/housing/index.htm).

[11] SBN 80 (1980) *Svensk Byggnorm med Kommentarer Chapter 33 Thermal Insulation and Airtightness*. Statens Planverk, Sweden.

[12] Phillips T, Rogers P and Smith N. 2011. Ageing and airtightness - How dwelling air permeability changes over time. National House Building Council Foundation.

[13] Zero Carbon Hub. 2009. *Indoor air quality in highly energy efficient homes – a review*. NHBS Foundation Report NF18.

[14]Davis I, Harvey V (2008). *Zero Carbon: what does it mean to homeowners and housebuilders?* NHBC Foundation report, NF9, April 2008.

[15] NHBC 2012 *Today's attitudes to low and zero carbon homes views of occupiers, house builders and housing associations* NHBC Foundation ISBN 978-1-84806-246-7
[16] Zero Carbon Hub 2012 *Mechanical ventilation with heat recovery in new homes – interim report*, NHBC Foundation ventilation and indoor air quality task group
[17] Sullivan L. 2007. *A Low Carbon Building Standards Strategy for Scotland*, Report of a panel appointed by Scottish Ministers Chaired by Lynne Sullivan 2007, Scottish Building Standards Agency. This document is available on the SBSA website: www.sbsa.gov.uk.

Questions	Answer
What are the benefits for builders or owners for implementing QM approaches?	*In relation to airtightness, quality is controlled by the requirements of the building regulations. Approximately 10 – 20% of buildings must be tested for airtightness. Failure to meet the airtightness requirement will result in extra cost through remedial actions and re-testing. This avoidance of extra cost is an incentive to ensure good site practice.*
Are there in your country companies involved in QM approaches for airtightness in the construction process?	*Guidelines for achieving air tightness are provided by the major associations such as the National House Builders Association. For example* *http://www.nhbc.co.uk/Builders/ProductsandServices/Airleakagetesting/DocumentlibraryALT/filedownload,38248,en.pdf*
Are there incentives for these QM approaches?	*The primary incentive is avoiding the cost of remedial work and re-testing.*
If yes,	
- Are there restrictions?	*N/A*
- How are they approved?	*N/A*
- How are they controlled?	*N/A*
Do you think such approaches have great/moderate/little potential for improving airtightness in practice?	*The legal requirement to meet the airtightness standard of the design, backed by testing, probably provides the best incentive.*
Do you think such approaches give greater confidence in the final airtightness? Has this been evaluated?	*N/A*
To your opinion, what are the pitfalls to avoid?	*N/A*
What is your general feeling about these approaches?	*This approach is widely accepted by the industry.*
List information and references (preferably in English) on this subject in your country	*ATTMA (2010) Measuring Air Permeability in the air envelopes of dwellings. Airtightness testing and measurement association*

Table 1. Summary of potential for improving airtightness through QM approaches in the UK.

Lessons learnt from the qualification of the airtightness testers and regulatory quality management scheme in France

Sarah Juricic*[1], Florent Boithias[1], and Joris Biaunier[1]

1 Centre d'Études Techniques de l'Équipement de Lyon
Boulevard Bernard Giberstein
71400 AUTUN Cedex, France

**Corresponding author:*
sarah.juricic@developpement-durable.gouv.fr

ABSTRACT

From January 1st 2013 on, the French energy performance regulation will demand that the airtightness level is justified and that airtightness of a building should be below 0,6m^3/h/m² at 4Pa for single family housing and 1M3/h/m² for multi-family dwellings, resulting into an important growth in the airtightness market. It is the role of the State to accompany this market evolution and to supervise the quality of airtightness measurements used for the EP calculation. This is why it has been decided that there are two possibilities to justify the airtightness level of a building. Either the constructor makes a systematic measurement of their building or the constructor proves they have a quality management system so that more than 85% of their production reaches the wanted airtightness.

In order to ensure the quality of airtightness measurements on the one hand and of quality management for airtightness on the other hand, two committees have been created. The first one is in charge of authorizing testers to perform official measurements. The second is in charge of authorizing constructors to justify airtightness by a quality management scheme. The CETE de Lyon has been in charge of the first in the past and is still in charge of the second.

This paper deals with both committees and discusses the advantages and issues raised by such authorities, thanks to the experience gained by the CETE de Lyon on these matters. There is no doubt that it is necessary to check on a regular basis the quality of the test reports produced by airtightness testers. As for the quality management for airtightness authorization, results show an improvement in the airtightness levels reached by authorized constructors. Flaws in the control process and biased tests show several possibilities for the State to improve the frame of this authorization.

KEYWORDS

Envelope airtightness, quality management, tester qualification

INTRODUCTION

With the future obligation to prove a certain level of compliance with the French Energy Performance Regulations, airtightness has got a key role in the construction field. Indeed, the application of the 2012 EP regulation demands that buildings comply with an airtightness level below 0,6m^3/h/m² at 4Pa for single family housing and 1M3/h/m² for multi-family dwellings. To prove the compliance, a constructor has two choices. Either they make a systematic measurement of their buildings or they prove by hand of a quality management process for airtightness that more than 85% of their production has the wanted airtightness.

To ensure quality of measurements and of quality management procedures, the State implemented two authorization procedures, which the CETE de Lyon was or still is in charge of.

This paper deals with both authorization committees and discusses the advantages and issues raised by such authorities. Finally this paper will try to give some answer to the question: is it worth it to implement such authorizations for airtightness measurements and for quality management schemes?

QUALIFICATION OF AIRTIGHTNESS TESTERS

Context

To ensure the quality of airtightness tests over the years, a state controlled qualification is necessary to perform an airtightness test destined to regulatory purposes. This qualification requires that the tester submits proof of training in the field of airtightness measurement and proof that the test reports they produce comply with the norm NF EN 13829 and its implementation guide GA P50-784.

Since January 2011, their application is received by the organism Qualibat. Qualibat is committed to sharing out the totality of the applications to experts designated by the State upon the advice of the CETE de Lyon. On expert submits an opinion on the test reports, which are read during committees. Meetings of the committee are organized by Qualibat. In the end, the committee states on the application by either giving an agreement to the tester, or asking for modifications on the test reports, or asking for new reports or else refusing the agreement. After the third review, if still not satisfying, the committee will very likely refuse the application anyway. When refused, the applicant has to submit a completely new application. The committee can also ask the applicant to attend a new training about airtightness measurement.

When an applicant receives an agreement, they are still committed to sending each year their test reports so that an expert can check that these reports still comply with the norm and the implementation guide. Again, if the reports do not, the committee can ask the tester to submit one or more new reports or to modify their test reports. If testers do not commit to the obligation to send follow ups, the committee will warn them and might suspend their agreement.

The process allows continuous check that the quality of the reports remains. Testers are committed to taking into account any new requirements set up by the committee or by the State. That they do in fact is checked every year during follow up reports handed in by the testers.

As of March 2012, the committee has approved of 320 testers. The committee has set a goal of 3000 approved testers by 2015 to follow the increase of tests needed.

Lessons learnt

Since Qualibat is in charge of organising the committee, testers have to pay a fee to Qualibat to get the agreement. Before 2011, the CETE de Lyon was in charge of the committee and did not ask for any fees. One of the consequences is that testers take extra care in their application when submitting an application to Qualibat. Hence 34% of applicants pass after the first review against 24% in 2009.

In general, we can also conclude that the role of the committee in checking the quality of the tests is necessary by looking at the number of follow ups that don't pass after first review by the committee. A large number, 69% of the follow ups does not pass after a first review. This number is biased by the fact that testers sending follow ups in 2011 received an agreement latest in December 2010, a time at which the committee was less harsh. It shows however that follow up is necessary to improve the quality of airtightness tests.

REGULATORY QUALITY MANAGEMENT SCHEME

Context

Quality management process for air tightness of buildings has been set up in order to improve air tightness treatment during all design and construction stages and in order to spread good practice among professionals.

The French 2005 energy performance regulation introduced the possibility to use an airtightness value lower than the default value in the EP-calculation. This possibility is given only if a measurement proves the lower airtightness value or if the constructer follows a State authorized quality management procedure for airtightness, without systematically performing a test.

Soon, the 2012 energy performance regulation, applicable from January 1st 2013 for housing, makes the air tightness test compulsory. The quality management process gives the applicants the possibility to reduce the amount of compulsory tests at commissioning since only minimum 5% of the production has to be tested. It gives also the possibility to make energy performance calculations with an air tightness factor lower than the regulatory 0, 6 $m^3/h/m^2$.

Requirements

Applications are sent to a specific committee dealing with the quality management procedure in airtightness. Any application has to include basic requirements linked to quality management approach, tests on a sample of the production and training documents focusing on airtightness destined to co-workers and craftsmen. Furthermore, some documents have to be submitted to the committee, among others:

- Identification of the chain of liabilities: who does what and when
- Description of the approach applied to the company
- Description of the design characteristics of the buildings on which the quality management approach applies
- Results of tests on a sample of the buildings production proving that more than 85% of the tests are below the target airtightness value

The 2012 quality management process will also require all documents produced in the frame of the quality approach for randomly selected buildings.

Results obtained by approved companies

So far, the committee received a few follow ups of applicants implementing a 2005 quality approach. The follow ups included bar charts of all measurements performed internally. A compilation of all charts can be seen in figure 1.

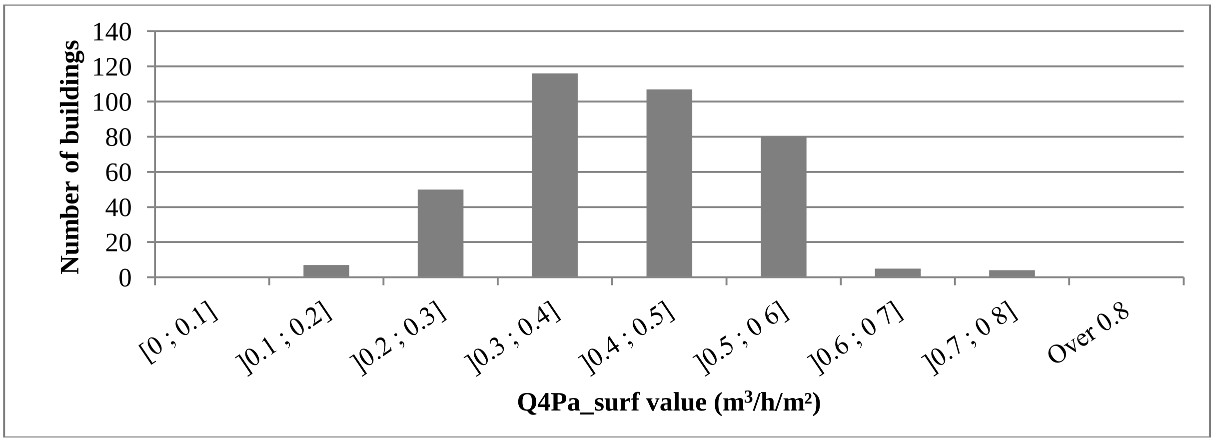

Figure 1: Follow up results declared by 14 applicant in 2011 (N=369)

Obviously, these results show that every single building tested by these 14 constructers scored below the Q_{4Pa_surf} target of 0,8 $m^3/h/m^2$. The bar chart also shows a normal distribution.

It has been said above that state authorized testers have to submit each year a list of all measurements they performed during the past year. So in order to evaluate the effectiveness of the quality approach, the results shown in figure 1 have been compared to more than 1000 in March 2012 available tests performed by state authorized testers. The comparison is given in figure 2.

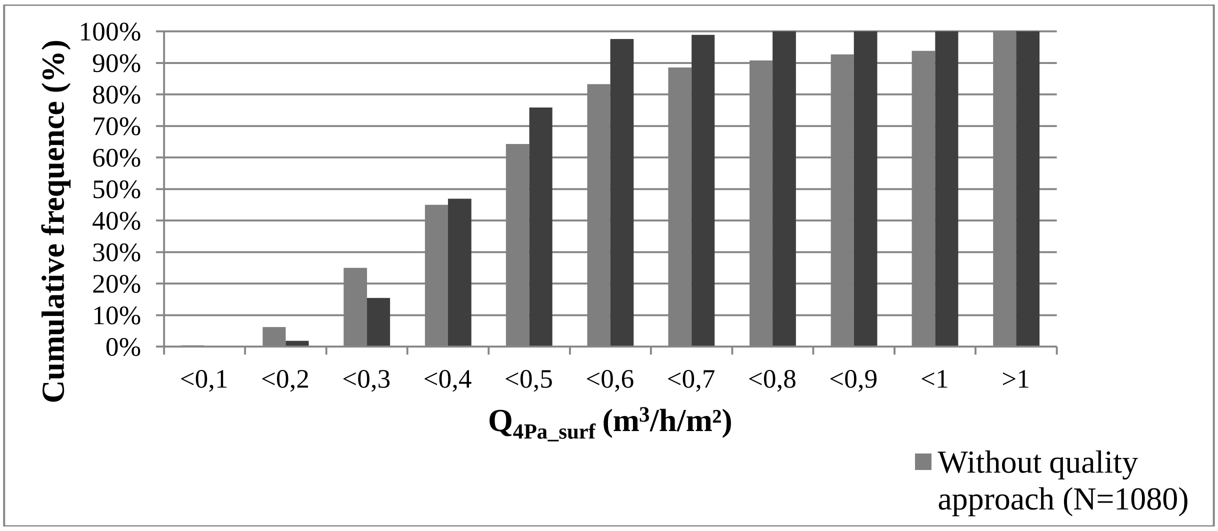

Figure 2: Distribution of measured airtightness with (dark grey) and without (light grey) approved quality management process

Figure 2 suggest that among the airtightness measurements performed in 2011, 100% of the tests on building with quality approach score below 0,8m3/h/m², whereas only 91% of all other tests do. Knowing that almost a half of the measurements performed without quality approach are candidate for the label BBC Effinergie, the 91% rate is optimistic.

Controls by state technicians

The results presented in figure 1 are based on measurements performed by State authorized testers. These testers however are not necessary independent of the applicant. Indeed, applicants get advice from ISO9001 bodies working in the field of airtightness that audit the applicants and most likely test the production of the applicant. The independence of the measure is therefore not guaranteed.

To avoid such a bias, the committee defined a control process. Every year, each applicant is asked to hand in a list of all buildings expected to be delivered in the coming year, including date of commissioning, name and address of the client. If the applicant is reluctant to pass the information, the applicant might see his agreement suspended.

A state technician performs control measurements on randomly selected buildings. The amount of buildings tested should cover more than 5% of all buildings delivered. As of March 2012, 28 control measurements have been performed.

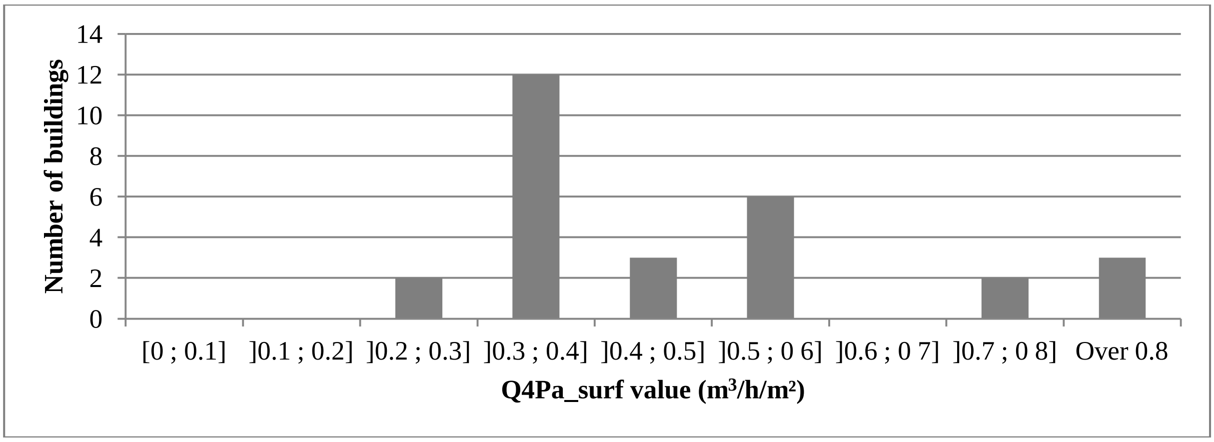

Figure 3: Results of the controls performed by the state technicians (Ntotal=28)

From figure 3 can be inferred that if most of the tests show a result lower than the target airtightness level, a few are above the wished Q_{4Pa_surf} of $0{,}8m^3/h/m^2$. This has a lot to do with the moment when the building is measured. Sometimes, at commissioning, the building is not quite finished because the client wants to install equipment themselves, like toilets or a wood-burning stove. The measurement method requires that the place left for these equipments must remain open, which means that the tester must not block it up. As a consequence, the airtightness level is seriously weakened. This specific point will be discussed later on. This being said, average and median value still comply with the expected level of airtightness, as can be seen in table 1.

Approved company	Building production for the year 2011	Expected Q_{4Pa_surf}	Amount of controls planned	Controller measured Q4Pa_surf: median	Controller measured Q4Pa_surf: average
1	54	0.8	4	***	***
2	102	0.8	5	***	***
3	1537	0.8	**	***	***
4	641	0.8	**	***	***
5	267	0.8	9	0.51	0.79
6	35	0.8	4	***	***
7	88	0.8	5	0.37	0.38
8	101	0.8	4	***	***
9	133	0.8	**	***	***
10	308	0.8	14	***	***
11	530	0.8	20	0.33	0.39
12	50	0.8	**	***	***
13	180	0.8	6	***	***
14	55	0.8	2	0.52	0.52
15	*	0.8	25	***	***
16	*	0.8	1	***	***

Table 1. Results measured by the controller

*Follow up reports for applicants 15 and 16 not yet received
** Company received agreement recently.
*** Control measures not performed yet.

Towards quality management process version 2012: lessons learnt so far

Already, companies can submit an application for a quality management process corresponding to the 2012 energy performance regulation. The committee is indeed processing some early applications. The experience gained from the 2005 agreement process and from the controls performed is useful to set up an efficient procedure.

As already mentioned above, buildings are not always completely finished when the keys are handed to the owner, for example clients take in charge bathrooms or chimney. As a consequence, testers should not seal the holes left because they have to comply to the norm NF EN 13829 and its implementation guide, which demand to leave the holes open, hence there are probably some improper measurements done internally, which gives a bias in the results showed by the constructer.

The committee discussed this point and decided that it is still the liability of the constructor to justify the level of airtightness at commissioning, even when holes are left open. The committee will therefore expect the following requirements to be fulfilled. The first possibility is to reach an airtightness level low enough even if the building is not yet finished. If not and/or if works are to be done in the house by the client, the constructor has to prove that those works are not a threat to the airtightness, and a test is performed after the works by the client. On the contrary, if the works are a threat, the test will still be done after finishing the works. Hence the constructor is expected to give a specific training about air permeability to the client so that they will not deteriorate the airtightness.

Another bias seen in the control tests performed by the state technician is that the controller is given name and address of clients with approximate date of commissioning by the constructor. The controller randomly selects buildings to test, but still relies on the constructor to visit the construction site. It has been seen that some controlled buildings have been “prepared” for the venue of the controller, with among others fresh foam material filling in vacant spaces for toilets. The test is done in the conditions the building has been delivered, but the real final airtightness value will be higher than what is measured, since the foam material is not meant to stay.

To improve the efficiency of the controls, it has been suggested that they should focus on buildings with sensible spots. We identified among others wooden intermediate floors or mechanical ventilation as quite difficult to apprehend from an airtightness point of view. If the focus is on buildings presenting that type of characteristics, it is to expect that the rest of the buildings production complies with the target airtightness level. Plus, the committee witnesses a growth in the number of applicants and with the application of the 2012 energy performance regulation; this number might grow even more. It will be difficult for control testers to measure more than 5% of the production. It is then all the more understandable to focus on sensible construction types.

Seeing that constructors having a quality management process succeed more easily to reach a target airtightness value raises an issue concerning other constructors. Every building will soon have to comply with the Q_{4Pa_surf} of $0{,}6 m^3/h/m^2$ but it is feared that without proper preparation especially in early design stage, it might be difficult for average constructor to obtain such airtightness results.

Finally, let us note that controls are informative. But what if in the future, controls show that an applicant does not comply with their own target? There are still questions here: will the company lose its agreement, will they be warned for a year, or will they have to hand in more documents?

CONCLUSION

With the January 1st 2013 deadline approaching, it is of the greatest importance to prepare the market for systematic airtightness measurements.

The choice to set up a national authorization process for airtightness measurements and for quality management schemes seem to be necessary to improve the quality of the measurements and to contribute spreading good practice in the field of airtightness.

At the same time, a great deal is put into knowing the difficulties testers and constructors might have. Surveys and feedbacks for applicants are options that might be used in the future to keep on improving the frame of authorization.

Questions	Answer
Is there a quality framework for airtightness testers in your country?	Qualification Qualibat 8771
If yes, - what were the reasons behind the development of these frameworks? - what is (are) the body(ies) that issue the certification or qualification?	 Need to have reliable measurements with the BBC-Effinergie low-energy label requirements for airtightness, generalized in the RT 2012 regulation Qualibat (association specialized in qualification and certification of building contractors)
Are there specific guidelines for performing or reporting the airtightness test beyond the requirements of EN 13829 or ISO 9972?	The implementation guide GA P50-784 completes the norm EN 13829.
Are there specific guidelines for the airtightness equipment and software beyond the EN or ISO standards requirements?	Equipment guidelines are specified in an implementation guide GA P50-784; they include a specific calibration procedure and the validation of the software with test examples.
What are the steps for a tester to be qualified/certified?	Attend a specific State authorized training, most of the time it is a three days training, then pass a theoretical test and pass a practical test. Next step is to submit an application to Qualibat, including five test reports.
How many testers are qualified according to this framework?	320 in March 2012
Is/are there a specific scheme(s) for airtightness test reporting? If yes, - What were the reasons behind the development of these schemes? - Does it include specific measures to guarantee the accuracy of the airtightness inputs in the EP calculation?	The test report must comply with formal requirements explained in GA P 50-784. Make the analysis of test reports easier for experts. Ensure all measurement details are included so that results can be checked Monitor the improvement of building airtightness at national level by demanding the same indicators in every test report All reports received yearly by Qualibat should include by the implementation guide required information that allows checking the calculations. Review of the reports ensures correct airtightness input in EP calculations.

- Does it include the collection of test reports by a central body? - Is there a monitoring scheme?	Mandatory annual follow ups transferred to Qualibat include a register of all tests performed in the past year and all test reports used in EP-calculations. Follow-up procedure demanding transmission of all test reports of the past year.
List information and references (preferably in English) on this subject in your country	NF EN 13829 GA P50-784 www.rt-batiment.fr (French) http://www.cete-lyon.developpement-durable.gouv.fr/etancheite-a-l-air-de-l-enveloppe-r127.html (French)

Table 2: Quality framework for tester authorization summary

Questions	Answer
What are the benefits for builders or owners for implementing QM approaches?	Stack the odds on their favour to reach the target airtightness value. Improve construction quality hence savings on customer service Non systematic measurement of the production hence savings for the company The QM approach is also used as a selling point.
Are there in your country companies involved in QM approaches for airtightness in the construction process?	Yes, in March 2012 there are 21 companies involved in a QM approach related to the 2005 EP regulation. One of them is also involved in a 2012 EP regulation QM approach. More companies are still in the reviewing process.
Are there incentives for these QM approaches?	Companies involved in a QM approach can use their airtightness target value in the EP calculations instead of the default value. Non systematic measurement of the production: measurements on a sample are sufficient.
If yes, - Are there restrictions? - How are they approved? - How are they controlled?	QM approach can only be implemented on housing. Companies submit their application to a specific committee, directed by a State representative and constituted of independent experts. Yearly follow up based on verification of all QM related documents and internal measurements performed. Controls are also performed by a state technician on randomly selected buildings.
Do you think such approaches have great/moderate/little potential for improving airtightness in practice?	Yes, QM approaches can quite improve the airtightness quality of buildings if it is correctly implemented in time. It also helps spreading good practice by demanding training of all workers involved in the construction loop.
Do you think such approaches give greater confidence in the final airtightness? Has this been evaluated?	QM approaches do ensure to a certain extent lower airtightness levels. However, controls show that the moment of measurement is critical: constructors sometimes leave works to do by the client which might worsen the airtightness.

To your opinion, what are the pitfalls to avoid?	Applications need to be carefully and deeply reviewed by experts that should have experience in quality management schemes in order to push the applicants to improve their approaches. Initiatives should be heartily approved for good ideas come out and improve the general authorization procedure.
What is your general feeling about these approaches?	Implementing a State controlled QM approach authorization is a quite heavy procedure but it certainly anticipates the soon to come obligation to perform under 0,6 m3/h/m² (resp. 1m3/h/m²) at 4Pa requirement for all new single dwellings (resp. multifamily dwellings). It helps spreading good practice and is a proof that reaching low airtightness results is definitely possible.
List information and references (preferably in English) on this subject in your country	www.rt-batiment.fr (French) Arrêté du 26 octobre 2010 relatif aux caractéristiques thermiques et aux exigences de performance énergétique des bâtiments nouveaux et des parties nouvelles de bâtiments, JO 27 octobre 2010 (French) Arrêté du 24 mai 2006 relatif aux caractéristiques thermiques des bâtiments nouveaux et des parties nouvelles de bâtiments, JO 25 mai 2006 (French)

Table 3: Quality management scheme for airtightness summary

ACKNOWLEDGMENTS

The sole responsibility for the content of this publication lies with the authors. It does not necessarily reflect the opinion of the Ministry.

SYSTEM FOR ENSURING RELIABLE AIRTIGHTNESS LEVEL IN JAPAN

Hiroshi Yoshino

Department of Architecture and Building Science,
Graduate School of Engineering,
Tohoku University
Aoba 6-6-11-1203, Sendai 980-8579
yoshino@sabine.pln.archi.tohoku.ac.jp

ABSTRACT

The energy-saving standard for housing in Japan was constituted in 1980 and revised in 1992. The expression of "Airtight House" was introduced in the revised standard. Since then, two different schemes appeared; one is the certification scheme for airtight house and the other one is the registration scheme for engineers for measuring airtightness of houses. These schemes have played an important role to ensure the quality of airtight houses so far. This paper describes the history of airtightness measurement in Japan and provides the outlines of certification scheme for airtight house and registration scheme of engineers for airtightness measurement, as well as the implemented measurement methods.

KEYWORDS

Airtight house, Certification system, Registration system, Assurance of airtightness

INTRODUCTION

The energy-saving standard for housing (Design and Construction Guidelines on the Rationalization of Energy Use for Houses) was initially constituted in 1980 and then revised in 1992. The expression of "Airtight House" was introduced in the revised standard. Since then, two different schemes appeared; one is the certification scheme for airtight house and the other one is the registration scheme for engineers for measuring airtightness of houses. These schemes have played an important role to ensure the quality of airtight houses so far. The number of registered engineers is 3375 in 2011 and the total number of airtight house certification was 57 in 1998. Since then the airtight certification was included in the certification scheme for houses satisfying the next-generation energy saving standard. The total number of this certification is 120 in 2011. These schemes have been playing an important role to ensure the quality of airtight houses so far.

DEVELOPMENT OF MEASUREMENT OF AIRTIGHTNESS

Studies of building air-tightness were initially carried out about 30 years ago in Japan by Narasaki and Kusumi [1], Murakami and Yoshino et al. [2,3] and Asano [4]. Murakami and Yoshino et al. examined the air-tightness of detached houses and found that the air-tightness was very different in the investigated houses where cracks were largely observed besides windows and external doors [2,3]. Based on the results, it was concluded that the air-tightness

varied depending on the accuracy of construction and it could not be defined without measurement.
As an indicator for evaluating building airtightness, it was proposed to define opening area that corresponded with the size of leakages, and also to describe using numerical value per floor area under the condition of 1 mmAq (9.8 Pa) which is the pressure difference in regular outdoor condition. This value of 1 mmAq (9.8 Pa) made the calculation of the corresponded opening area easy, and it has been commonly adopted to evaluate the air-tightness of buildings in Japan since then.

ENERGY-SAVING STANDARD WITH AIRTIGHT HOUSE

The expression of "Airtight House" was firstly appeared in the revised standard. It is defined as the building should have corresponded leakage area less than 5 cm^2/m^2. It was described that the houses in Hokkaido (the northernmost territory of Japan) and in the three northern prefectures of Tohoku Region (northeastern area of Japan) must meet this criterion. Although this standard is not enforceable, it has been implemented to houses which are subjected under housing loan program from Housing Finance Corporation.
The energy-saving standard was revised again in 1999 under the influence of the prevention of global warming. The value corresponded to less than 2 $cm^2/m^2$of leakage area has been standardized for Hokkaido and the three northern prefectures in Tohoku, while the value of less than 5 cm^2/m^2 has been standardized for other areas and has been the criterion for the rest of Japan.
The standard was revised again in 2008 under the further pressure of the prevention of global warming. Unfortunately, the provision of airtightness faded away because it was said that the newly constructed houses are enough airtight and it is not necessary to prescribe the airtight house in the Standard.

CERTIFICATION SYSTEM OF AIRTIGHT HOUSE

Institute for Building Environment and Energy Conservation (IBEC) has provided the certification system for 'Airtight House' soon after the revision of 1992 and endeavored popularization of airtight house. The purpose of the system is to certify the house that is constructed as an airtight house by the designated methods, which are evaluated by the reviewers using the data to satisfy an airtightness level and to be guaranteed to have stable performance.
In the certification system, three levels of air-tightness; A, B and C, were provided and each corresponded leakage area was set to be 5, 2 and 1 cm^2/m^2 respectively, which are roughly equal to the air change rates of 1.5, 3.0, 7.5 ACH at the indoor-outdoor pressure difference of 50 Pa respectively. The acknowledged housing systems with certification are now about 170. Most of the houses in Japan have the level of less than 5 cm^2/m^2, and the level of less than 2 cm^2/m^2 has become common for buildings when considering air-tightness.
Housing companies and builders submit the documents with measurement results of airtightness performance to the IBEC. The members of jury review the documents and the committee finally judges whether it is accepted or not. If it is accepted, the certification is issued to the submitters. The total number of airtight houses constructed with the certification system is around 90,000 in 1998. There is no data available after that.
The items which is included in the documents are shown in Table 1.

1. Information for airtightness performance
   1) Airtightness performance level and measure data

Level A (less than 5 cm^2/m^2): Data of measurement results for more than 3 houses are required.
Level B (less than 2 cm^2/m^2):Data of measurement results for either of 10 houses or 10% of constructed houses, which is larger are required.
Level C (Less than 1 cm^2/m^2): Data of measurement results for either of 10 houses or 20% of constructed houses, which is larger are required.

   2) Measurement methods

Pressurization or depressurization method.

   3) Measurement instrument

The measurement should be performed by using the designated instrument which is assigned by the Japan Testing Center for Construction Materials or institutes.

   4) Contents of measurement results
      a) Name of registered tester of airtightness.
      b) Name of house measured, location, date of measurement.
      c) Structure, construction methods, floor plan and sections showing the locations of indoor and outdoor pressure taps, airflow rate measurement, specification of windows, air inlets and air barriers etc.
      d) Weather conditions including wind speed, wind direction and indoor/outdoor temperatures.
      e) Type of measurement instrument, date of examination, name of examination institution.
      f) State of opening and sealing for windows, inlets and outlets, vents and other openings installed in the building envelope.
      g) Name of spaces excluded for measurement.
      h) Table of measurement results (more than three points) for pressure difference and airflow volume, and the chart showing the relationship.
      i) Coefficients of leakage equation expressing the relationship between pressure difference and airflow rate, equivalent leakage area, equivalent leakage area per floor area.
2. Information for component materials for making airtight
   1) Name of goods: Name of material, Number of Japanese Industrial Standard corresponded.
   2) Physical features: Shape and size, Thickness, Strength, Vapor permeance, Durability, Safety.
   3) Construction: Procedures of construction, Instruments used, Idea for construction, Safety and no-pollution.
3. Information for airtightness design
   1) Design concept: Fundamental design concept, Points to be paid attention.
   2) Design manuals.
   3) Specifications related to a whole building, airtightness and ventilation.
   4) Drawings: Plans, Sections, Details including connections between components.
4. Systems of supply, construction, services, guarantees
   1) Supply system including quality control and responsibility of physical distribution
   2) Construction system: Sharing of construction responsibility, Manual of construction and way to use, Education system of construction, Checking system after the construction.
   3) Service and guarantee system including treatment of claims and manuals for occupants.

Table 1. Contents of documents to be submitted for certification of airtight house

REGISTRATION SYSTEM OF ENGINEERS FOR AIRTIGHTNESS MEASUREMENT

Since 1998, the engineers who were trained by IBEC for measuring airtightness in houses were required to register with the registration scheme. It is because, to ensure the highest quality assurance, only the registered engineers are qualified for the implementation of the measurement test and issued certification of airtight house. On the other hand, the second reason is to popularize appropriate technology of air-tightness measurement nationwide. The number of engineers registered with certificate has reached 3,800 in May, 2008.
Engineers, who want to be registered, should participate in the class and exercise before the examination. In addition, they should be either first class or second class registered architects, or registered building service engineers or registered engineers' by The Society of Heating, Air-Conditioning and Sanitary Engineers, Japan. However, engineers with over 5 years of

experience in airtightness measurement, construction of airtight houses and other works related to airtight houses are also qualified for examination.
The contents of the course includes the following items in lectures and exercises;
1) Fundamental knowledge of airtightness and ventilation performance.
2) Introduction and application of airtightness and airtightness measurement methods.
3) Mechanism of measurement instrument.
4) Exercise of airtightness measurement.

METHODS OF AIRTIGHTNESS MEASUREMENT

In Japan, the method of airtightness measurement was constituted in 2003, known as JIS (Japanese Industrial Standard) A2201. All the measurements should follow this standard. Main points for measurement are as follows;
1) Sealing conditions at measurement
   Leaks such as ventilation inlets and outlets, mechanical fans, vents for exhausting combustion gass can be sealed.
2) Outdoor wind speed
   Measurement should be done under the condition of no wind in principle. However, it is allowed to have the condition where the pressure difference by the outdoor wind is less than 3 Pa.
3) Indoor temperature
   Measurement can be done under the condition of indoor temperature between 5 and 35℃.
4) Pressure difference between indoor and outdoor
   In order to prevent the influence of stack effect, the measurement should be done under the condition that the value of indoor and outdoor temperature difference (K) multiplied by the building height (m) (height of a unit in the case of apartment house) is less than 200 (Km).
5) The number of times of measurement
   For obtaining the results of airtightness performance, measurement should be done at least five times in the pressure difference between 10 and 50 Pa.

EFFECTIVE FACTORS OF AIRTIGHTNESS

Pressurized Method and Depressurized Method

In this category, the pressurized method keeps the indoor air pressure higher than the outdoor pressure while the depressurized method keeps the indoor pressure lower than the outdoor pressure. The leakage area considered in the pressurized method is larger than that of depressurized method because the force from indoor inflates the building envelope. The measuring data obtained from previous studies found that the airtightness level by the pressurized method was 100 – 120% of that by depressurized method [5]. As engineers and equipment can be influenced by outdoor coldness in case of pressurized method, JIS does not decide which of methods should be selected.

Changes of Airtightness in Time

It has been proved that the performance of air-tightness declines due to the dryness of building materials (e.g. lumber) and the frequency of opening and closing of windows/doors. Two different measurements were carried out by Irie and Fukushima et al. [6]; soon after the completion and one year later, in nine houses in Japan, and described that the leackage area has been increased about 100cm^2. And also similar measurements were carried out in U.K. [7] and Sweden [8]. New large-scale measurement data is necessary as the past data are old.

Influence of Humidity

The opening area gets influenced by the expansion and contraction of materials, especially in wooden houses. There are very few measurements on seasonal changes of air-tightness, however there are some measured data available in Canada [9], England [10] and Japan [11]. All of the measurements showed that the openings became smaller right after the end of humid summer and became bigger right after the end of dry winter. The amount of seasonal changes is very different depending on measurement. In the measurement results done by Yoshino et al. [11], the seasonal changes were ±20% of the average of the year. This is considered to be very big, and accumulation of new data for this measurement is also necessary.

SUBJECTS IN FUTURE

The method of airtightness measurement in buildings are now available for use, however, the method of building elements should be developed.As for the data of airtightness, it is necessary to accumulate data related to deterioration from passage and influence from humidity.

CONCLUSION

1) In Japan, studies of building air-tightness were initially commenced 37 years ago. The development of indicator for air-tightness evaluation using corresponded crack area was proposed by Murakami and Yoshino and others.
2) Soon after the energy-saving standard for housing was revised in 1992, two different schemes appeared; one is the certification scheme for airtight house and the other one is the registration scheme for engineers for measuring airtightness of houses. These schemes have played an important role to ensure the quality of airtight houses so far.
3) Subjects in the future related to airtightness are that the method of building elements is developed, and that accumulate data related to deterioration from passage and influence from humidity.

REFERENCES

[1] Narasaki, M. &Kusumi T 1974. *Investigation on Air-tightness of Industrialized Houses.* Report for the annual meeting of Architectural Institute of Japan, 241-243 (in Japanese)

[2] Sugiyama, E., Murakami, S. & Yoshino, H. 1975. *Air-tightness Measurement of Building Elements of Industrialized Houses*, Report for the annual meeting of Architectural Institute of Japan, 253-254 (in Japanese)

[3] Ohta, K., Murakami, S. & Yoshino, H. 1976. *Air-tightness Measurement of Building Elements of Industrialized Houses*, Part 2, Report for the annual meeting of Architectural Institute of Japan, 225-226 (in Japanese)

[4] Asano, K. 1977. *Ventilation Characteristics of Multi-family Dwellings*, Journal of Heating, Air-Conditioning and Sanitary Engineerings of Japan 51, No.8, 51-56 (in Japanese)

[5] Kim, J. Y., Nagatomo, M., Yoshino, H. and Akabayashi, S. 1992. *Comparison of Pressurization and Depressurization Method in Measurement of Airtightness*, Report for the annual meeting of Architectural Institute of Japan, 615-616 (in Japanese)

[6] Irie, Y. & Fukushima, A. et al., 1990. *Air-tightness of Single Detached Houses in Hokkaido,* Report for the annual meeting of Architectural Institute of Japan, 565-566 (in Japanese)

[7] O'Sullivan, P. and Jones, P. J. 1982. *The ventilation performance of houses-A case study*, Proceedings of 3rd Air Infiltration Centre Conference
[8] Elmroth, A. 1981. *Airtight houses and energy consumption*, Building Research and Practice
[9] Kim, A. K. & Shaw, C. Y. 1984. *Seasonal Validation in Air-tightness of Two Detached Houses*, Measured Air Leakage of Buildings, American Society for Testing and Materials
[10] Warren, P. R. & Webb, B. C. 1980. *Ventilation Measurements in Housing*, Building Research Establishment, Department of the Environment
[11] Hasegawa, K. & Yoshino, H. et al. 1992. *Investigation of Indoor Environment of R-2000 Experimental House – Air-tightness*, Indoor Thermal Environment and Energy Consumption, Report for the annual meeting of Architectural Institute of Japan, 747-748 (in Japanese)

Questions	Answer
Is there a quality framework for airtightness testers in your country?	*Yes, we have. Since 1998, the engineers who measure airtightness of houses are required to register with the registration scheme.*
If yes, - what were the reasons behind the development of these frameworks? - what is (are) the body(ies) that issue the certification or qualification?	 *Need to ensure the highest quality assurance.* *Institute for Building Environment and Energy Conservation.*
Are there specific guidelines for performing or reporting the airtightness test beyond the requirements of EN 13829 or ISO 9972?	*Yes, we have JIS (Japanese Industrial Standard) A2201, which is reflected by ISO9972.*
Are there specific guidelines for the airtightness equipment and software beyond the EN or ISO standards requirements?	*The measurement should be performed by using the designated instrument which is assigned by the Japan Testing Center for Construction Materials or institutes.*
What are the steps for a tester to be qualified/certified?	*Engineers, who want to be registered, should participate in the class and exercise in one day before the examination.*
How many testers are qualified according to this framework?	*About 3800*
Is/are there a specific scheme(s) for airtightness test reporting? If yes, - What were the reasons behind the development of these schemes? - Does it include specific measures to guarantee the accuracy of the airtightness inputs in the EP calculation? - Does it include the collection of test reports by a central body? - Is there a monitoring scheme?	*The test report must comply with formal requirements explained in JIS A2201* *To ease experts analyse reports for qualification and to strengthen the reliability of the results* *No.* *No.* *No.*
List information and references (preferably in English) on this subject in your country	*JIS A2201* *Test Methods for Airtightness of Houses, IBEC*

Table 2. Summary of concerns and lessons learnt regarding reliable airtightness testing and reporting in Japan

Questions	Answer
What are the benefits for builders or owners for implementing QM approaches?	*Make sure that you will reach the expected performance*
Are there in your country companies involved in QM approaches for airtightness in the construction process?	*Yes. No detailed information.*
Are there incentives for these QM approaches?	*Yes. To obtain the airtight house certification*
If yes,	
- Are there restrictions?	*Any residential buildings*
- How are they approved?	*Housing companies and builders submit the documents with measurement results of airtightness performance to the IBEC. The members of jury review the documents and the committee finally judges whether it is accepted or not.*
- How are they controlled?	*The document includes measured data, measurement methods, results and so on for ensuring the airtightness quality.*
Do you think such approaches have great/moderate/little potential for improving airtightness in practice?	*Yes. Those are great potential.*
Do you think such approaches give greater confidence in the final airtightness? Has this been evaluated?	*Yes.* *But no evaluated.*
To your opinion, what are the pitfalls to avoid?	*No idea.*
What is your general feeling about these approaches?	*These approaches is very effective.*
List information and references (preferably in English) on this subject in your country	*Many books available. From Design of Insulation to Construction for Residential Buildings, IBEC*

Table 3. Summary of potential for improving airtightness through QM approaches in Japan

ACHIEVING GOOD AIR TIGHTNESS IN NEW AND RETROFITTED US ARMY BUILDINGS

Alexander Zhivov*1, Dale Herron1, J. Lee Durston2 and Matthew Heron3

[1]*US Army Engineer Research and Development Center*
Construction Engineering Research Laboratory
2902 Newmark Drive, Champaign, Illinois 61826, USA
**Corresponding author:*
Alexander.M.Zhivov@usace.army.mil

[2]*BCRA*
2106 Pacific Avenue, Suite 300
Tacoma, Washington 98402, USA

[3]*Pie Consulting & Engineering*
Joyce Drive, Suite 200, Arvada, Colorado 80403, USA

ABSTRACT

All Army facilities have been required to increasingly reduce site and source energy use. Along with improvements in energy consumption, building performance in hot humid climates has been a major concern of the Army. Barracks facilities in these environments often experience significant problems with interior mold and mildew as a result of the inability to control relative humidity within the buildings. The major problem is created by a combination of leaky buildings and air-conditioning systems operating at supply air temperatures below the dew point temperature. The Army has been investing large sums of money to remediate mold and mildew damage and maintain these facilities in a healthful and comfortable state.

During the past several years ERDC CERL has been conducting investigations to develop design/construction strategies for improving the energy efficiency, preventing mold, and improving indoor air quality in newly constructed buildings and buildings undergoing major renovations. An important part of these studies was building envelope leakage tests on some existing facilities to gain a better understanding of the general leakiness of Army buildings and the effect of increased air tightness on the building energy consumption. Based on the results of these studies, air tightness criteria and performance requirements to new construction and major renovation projects have been developed and included in the Army design/construction strategies.

Since 2009, the US Army Corps of Engineers (USACE) implemented a requirement for air tightness in all new construction and building enclosure renovation projects. This requirement set levels of air tightness for the building enclosure at the material, assembly, and system level. Additionally, it requires that a whole building air leakage test be completed at completion of construction to verify performance of the constructed air barrier system. This paper presents results of air tightness tests for more than 250 newly constructed and renovated large buildings from before and after new requirements were set, and analyzes the design and construction process, air barrier materials, building use, and construction types. The paper also shows simulation results that illustrate the effects of air tightness on the building energy use for two types of buildings in 15 representative US and 16 Canadian and European climate conditions. The data presented may support future decisions regarding air tightness levels to be adopted for commercial buildings.

KEYWORDS
Air tightness, air barrier testing protocol, energy conservation

INTRODUCTION

All Army facilities have been required to increasingly reduce site energy consumption in response to EPACT 2005, ECB 2010-14, and also the Army Sustainable Design and Development Policy Update (Environmental and Energy Performance, October 27, 2010).

EPACT 2005 required new facilities to reduce site energy consumption, not including plug and process loads, by 30% compared to a baseline facility designed in accordance with the minimum requirements of ASHRAE 90.1-2004, if life cycle cost effective. The Army Sustainable Design and Development Policy Update (Environmental and Energy Performance, October 27, 2010) requires new facilities to achieve reduced energy consumption at or below the levels specified in ASHRAE 189.1 Section 7.

To comply with the requirements of EISA 2007 to eventually eliminate fossil fuel use, new Army buildings and buildings undergoing major renovations shall be designed so that consumption of energy generated by fossil fuels (including electricity generated by fossil fuels) is reduced, as compared to energy consumption by a similar building in Fiscal Year 2003 (FY03) (as measured by the Commercial Buildings Energy Consumption Survey or Residential Energy Consumption Survey data from the Energy Information Agency), by 55% starting 2010, 65% - 2015, 80% - 2020, 90% -2025, and by 100% starting 2030. Meeting FY10 EISA 2007 fossil fuel-based energy use reduction will, in most cases, automatically result in compliance with the building site energy use reduction.

Along with improvements in energy consumption, building performance in hot humid climates has been a major concern of the Army. Barracks facilities in these environments often experience significant problems with interior mold and mildew as a result of the inability to control relative humidity within the buildings. The major problem is created by a combination of leaky buildings and air-conditioning systems operating at supply air temperatures below the dew point temperature. The Army has been investing large sums of money to remediate mold and mildew damage and maintain these facilities in a healthful and comfortable state.

PRELIMINARY ERDC STUDIES

Field Tests. During the past several years ERDC CERL has been conducting investigations to develop design/construction strategies for improving the energy efficiency, and for preventing mold and improving indoor air quality in newly constructed buildings and buildings undergoing major renovations. In the course of these studies, it became clear that building envelope air leakage needs to be addressed. To this end, ERDC-CERL has conducted building envelope leakage tests on some existing facilities to gain a better understanding of the general leakiness of Army buildings, to analyze the effect of increased air tightness on the building energy consumption, and to develop air tightness criteria and performance requirements to be included into the design/construction strategies.

Table 1 lists results of a sample of tested buildings, including four barracks buildings with interior entry ways (older buildings A, B, and C, and a newly constructed building D), a modular barracks building (building G), newly constructed dining facility (building E), and a two storey classroom training facility constructed in 1997 (Building F).

	Envelope Surface Area		Envelope Volume		Envelope Air Leakage
Bldg	sq ft	(m^2)	cu ft	(m^3)	@ 75 Pa (cu ft/min-sq ft)
A	23,300	(2,167)	137,300	(3,844)	0.57
B	37,200	(3,460)	269,100	(7,535)	0.56
C	33,600	(3,125)	230,200	(6,446)	0.77
D	55,000	(5,115)	590,200	(16,526)	0.65
E	80,700	(7,5050	690,000	(19,320)	0.63
F	43,000	(3,999)	345,000	(9,660)	0.28
G	9,700	(902)	**		0.38

Table 1. Test results for selected Army buildings.

Envelope surface area is defined as the sum of the areas of walls, lowest floor slab, and roof or ceiling. Data shows that the envelope leakage in Bldgs A, B, C, and D was in the range 0.56-0.77 cfm/sq ft (@ 0.3 in. of water (75 PA) pressure difference. The envelope of the modular barracks (Bldg G) had an air leakage of 0.38 cfm/sq ft. The newly constructed barracks (Bldg D) was no tighter than the other barracks that were constructed 30 years earlier. When examining the data for two buildings of like construction and configuration (Bldgs B and C), the renovated Bldg C is more than a third leakier than the unrenovated Bldg B due to poor sealing of penetrations through building structure elements. An analysis of data from 139 commercial and institutional buildings in the United States (Persily) revealed that the mean value of their envelope air leakage was 1.48 cfm/sq ft. These buildings ranged in age from 4 years to several decades. The seven Army buildings that were tested were all below this value indicating that typical Army construction is certainly no less airtight than other US buildings. However, only two of the tested Army buildings meet 0.40 cfm/sq ft requirement of recently adopted ASHRAE Standard 189.1 for Design of High Performance Green Buildings and the International Energy Conservation Code (IECC) 2012.

Computer Simulation Analysis. To estimate the achievable savings from reduced air leakage in newly constructed and retrofitted buildings, ERDC and National Renewable Energy Laboratory (NREL) researchers conducted simulation studies using the EnergyPlus 3.0 building energy simulation software. The baseline building was assumed to be an existing barracks, dormitory or multi-family building built to meet the minimum requirements of ASHRAE Standard 90.1-1989 (ASHRAE 1989) by climate zone. The barracks are three stories high with an area of 30,465 sq ft (2,691 m^2) and include 40 two-bedroom apartment units, a lobby on the main floor, and laundry rooms on each floor. Benne (2009) includes further details on the barracks and the baseline heating, ventilation, and air-conditioning (HVAC) systems used. Note that energy costs used in this study are based on Energy Information Administration (EIA) 2007 average data for commercial rates in each state and may not reflect the utility rates at a specific location (EIA 2008).

Four representative air tightness levels were modeled: 1.0, 0.5, 0.25 and 0.15 cu ft/m-sq ft (@ 75 PA pressure difference). The first value is used as the baseline and comes from expert opinion of existing buildings based on pressurization tests. The other three values are considered to represent reasonable performance improvements achievable with a low, medium, and a best effort for sealing existing buildings.

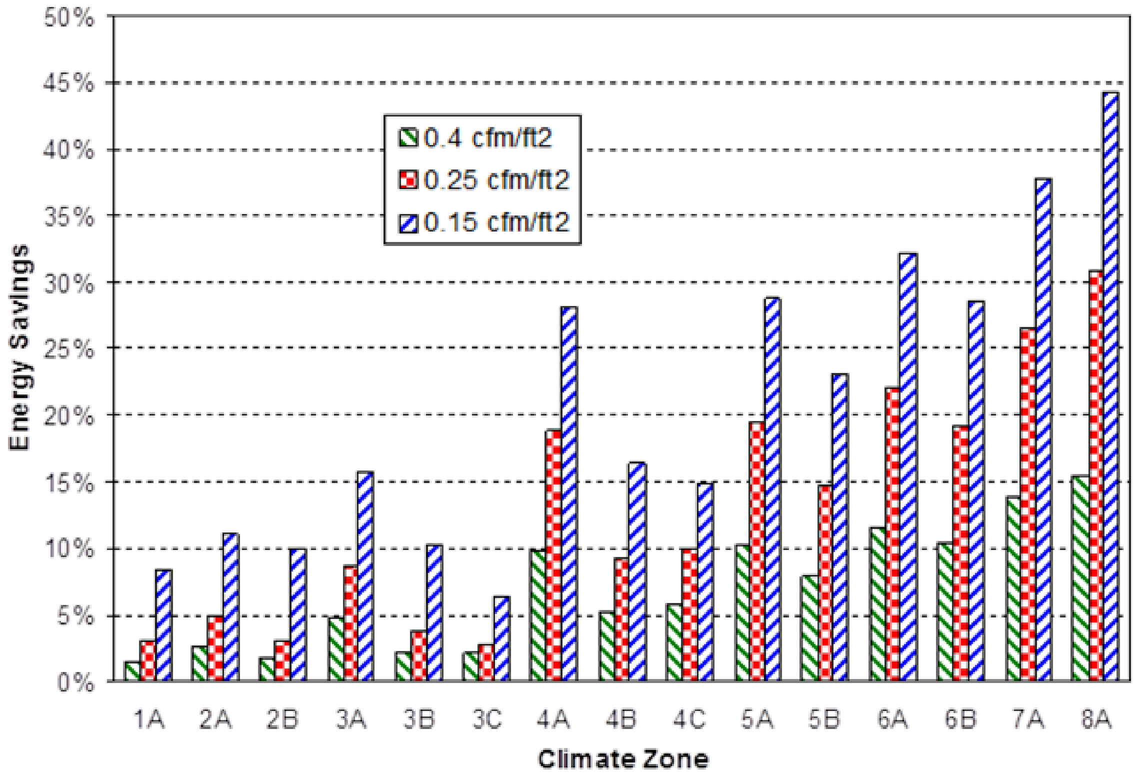

Figure 1. Percent annual energy savings in a barracks building due to air tightness improvement for US climate zones.

Figure 1 shows the results of analysis for improving the building air tightness for each climate zone. The energy savings are based on total building site energy consumption. Energy savings of range between 2% and 16% with the air tightness improvement to 0.4 cfm/sq ft at 75 PA, between 3% and 31% (0.25 cfm/sq ft) and between 8% and 44% with the air tightness at 0.15 cfm/sq ft. The highest results are achieved in the coldest climates and decrease in warmer climates. These savings translate to roughly $0.10-0.50 per sq ft. The results can vary with the change of baseline building air tightness, types of HVAC systems used, and energy rates.

For the economic analysis of air tightness improvement in buildings undergoing renovation, it was assumed that the air leakage rate of the modeled building can be reduced to 0.40 cfm/sq ft at a cost of $15,700 which includes attic sealing ($8,200) and a top floor sealing ($7,500). To reduce air leakage rate to 0.25 cfm/sq ft, additional weatherization of the two bottom floors and sealing doorways would be required and will add approximately $18,440, with a total retrofit cost of $34,140. These costs will be significantly lower if tightening of the building envelope will be a part of a more comprehensive retrofit project, which includes other measures (e.g., building envelope insulation, replacement of window, etc.). Figure 2 shows that improving building air tightness with building retrofits has a reasonable payback (<10 years) in all climate zones.

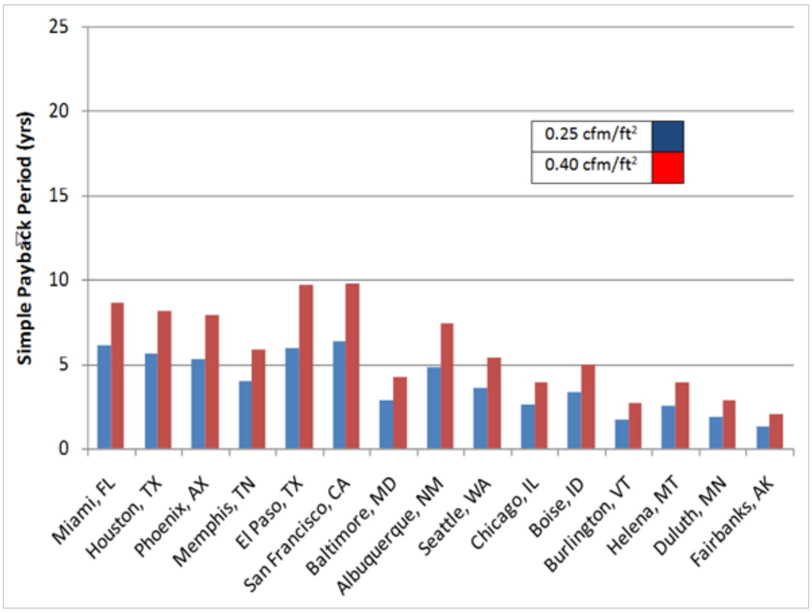

Figure 2. Average simple payback period in a barracks building due to air tightness improvement for US climate zones.

USACE REQUIREMENT FOR AIR BARRIERS AND WHOLE BUILDING TESTING

Based on the results of these studies, the US Army Corps of Engineers set a requirement (ECB 29-2009) that all new buildings and buildings undergoing major renovation shall pass an air leakage test where the results are less than or equal to 0.25 cfm per square foot of exterior envelope at 0.3 in. of water gage (75 Pa) pressure difference. If a building is found to leak more air than this rate, it is considered a “failed” test and the contractor must find and fix air leaks until the building reaches the “passing” level. The test is to be performed according to the protocol developed by USACE ERDC together with Air Barrier Association of America (ABAA) and industry partners. For comparison, Table 2 lists this requirement with other national and international standards.

ECB 29-2009 also requires a thermographic survey of the completed building in accordance with ASTM E 1186 using infrared cameras with a resolution of 0.1 °C or better. IR testing is required to determine the major remaining air leakage pathways and perform corrective work as necessary to achieve the whole building air leakage rate specified in above.

Country	Source	Requirement*	cfm/sq ft @75Pa
USA	ASHRAE 189.1-2009/IECC 2012		0.40
UK	TS-1 Commercial Best Practice	5 $m^3/h/m^2$ at 50 Pa	0.36
USA	LEED	1.25 sq in EqLA @ 4 Pa / 100 sq ft	0.30
Germany	DIN 4108-2	1.5 1/h at 50 Pa	0.28
UK	TS-1Commercial Tight	2 $m^3/h/m^2$ at 50 Pa	0.14
CAN	R-2000	1 sq in EqLA @10 Pa /100 sq ft	0.13
Germany	Passive House Std	0.6 1/h at 50 Pa	0.11
*USACE Requirement is 0.25 cfm/sq ft at 75 Pa			

Table 2. Air Tightness Standards Comparison (For a four-story building, 120 x 110 ft, n=0.65).

Other major requirements to the air barrier established by ABAA include:

- Air barrier must be continuous, with all joints sealed.
- The materials shall have an air permeability not to exceed 0.004 cfm/sq ft under a pressure differential of 0.3 in. of water. (Or 0.02 $L/s/m^2$ @ 75 Pa)
- It shall be capable of withstanding positive and negative combined design, wind, fan and stack pressures on the envelope without damage or displacement, and shall transfer the load to the structure. It shall not displace adjacent materials under full load.
- It shall be durable and maintainable.
- The air barrier shall be joined in an airtight and flexible manner to the air barrier of adjacent systems, allowing for the relative movement of systems due to thermal and moisture variations and creep. Connections shall be made between: foundations and walls, walls and windows or doors, different wall systems, wall and roof, wall and roof over conditioned space, walls to floor and roof across construction, control and expansion joints, walls floor and roof to utility pipe and penetrations.

Since introduction of the requirements to air barrier and a maximum allowable air leakage rate in 2009, more than 250 newly constructed and renovated buildings have been tested to meet or significantly exceed these requirements. Most of them were proven to have an air leakage rate between 0.05 and 0.25 cfm/sq ft at a pressure difference of 75Pa during the first test (see Table 3). Few buildings, usually those where there was insufficient consideration for the air barrier in design and construction, have to be sealed and re-tested to meet these requirements.

ANALYSIS OF THE SAMPLE OF 200 LARGE BUILDINGS AIR LEAKAGE TESTING RESULTS

The following discussion is based on results of tests performed by BCRA Inc. and Pie Consulting & Engineering on 200 buildings built and retrofitted to meet the USACE requirement. Some of these buildings were among the first to include the Building Air Tightness requirement in the RFP while others represent projects with design-build teams that had already learned lessons on buildings with the requirement. The subject buildings represent projects that completed final testing over a range of 29 months and represent buildings from 34 DoD installations and different US climate zones. Although all buildings or air barrier zones reported on qualify as commercial construction, buildings included in this study ranged from one to eight stories and building envelope areas ranging from 1,000 to 370,000 sq ft.

Location	Building Type	Air Barrier Envelope Size		Result		% Better than 0.25 CFM/sq ft (0.132 ($m^3/min/m^2$))
		sq ft	(m^2)	CFM/sq ft	($m^3/min/m^2$)	
Ft. Bliss, TX	Barracks	71,312	(6,632)	0.05	(0.026)	81%
Ft. Bliss, TX	Barracks	71,312	(6,632)	0.06	(0.032)	76%
Ft. Sam Houston, TX	Medical Education and Training, Dorm	371,099	(34,512)	0.07	(0.037)	73%
Ft. Bliss, TX	Barracks	71,312	(6,632)	0.07	(0.037)	72%
Ft. Bliss, TX	Barracks	72,573	(6,749)	0.10	(0.053)	62%
Ft. Polk, LA	Barracks (Renovation)	52,476	(4,880)	0.10	(0.053)	60%
Ft. Sam Houston, TX	Medical Education and Training, Dorm	141,893	(13,196)	0.10	(0.053)	60%
Ft. Bliss, TX	Maintenance Facility	24,632	(2,290)	0.13	(0.068)	48%
Ft. Riley, KS	Company Operations	43,115	(4,010)	0.14	(0.074)	44%
Ft. Leonard Wood, MO	Battalion HQ	63,276	(5,885)	0.14	(0.074)	44%

Table 3. Sample of test results.

In addition to simply reporting the results of the testing, information was gathered regarding how the air barrier requirement was addressed in the design-build delivery process. Information was gathered on construction type, building use, as well as what air barrier materials, assemblies, and systems were utilized. Variables recorded for each building include:

- Date Tested
- Location
- Gross Floor Area
- Number of Floor Levels
- Area of Building Envelope (Pressure Boundary)
- Building Use
- Construction Type
- Envelope Consultant Incorporated Holistically (DD, DQC, CQC, Cx)
- Envelope Consultant Incorporated to perform Independent Technical Review of
- Envelope Design Documents (DQC)
- Envelope Consultant Incorporated to perform Construction Quality Control Site Visits (CQC)
- Typical Wall Air Barrier System Type
- Typical Roof/Lid Air Barrier System Type.

Major trends realized from the data set are:

1. **Achievable.** The first major trend is the fact that, of the 200 building tests performed and analyzed, all but a few were able to meet the USACE air leakage requirement of 0.25cfm/sq ft @75Pa. Three years ago, most design and construction professionals had little idea of what a continuous air barrier was, how to implement it, or even what a good air leakage rate would be. ASHRAE has struggled for years to put an appropriate number on envelope air tightness levels. The industry simply knew that air leakage had serious negative impacts on building durability and energy use and that it should be limited. So when USACE set forward the air leakage requirement in 2009, it was met with some resistance. Additionally, the learning curve for design-build teams to successfully implement air barrier strategies proved to be quite small. Average results of the first 200 buildings tested for the USACE proved to be 0.17cfm/sq ft @75Pa.

2. **Applicable.** The industry also called into question that the same allowable leakage rate was applied to buildings of all types and uses, over differing climate zones, and varying building sizes (gross floor area and height). Test results indicate that all buildings were able to meet the requirement regardless of size, location, construction type, and most importantly, building use. Figures 3 to 10 show examples of diverse building types that met the USACE air leakage requirement. On each building, whole building air leakage testing was performed in accordance with the USACE Protocol for Large Building Air Leakage Testing.

Figure 3. USACE Admin Bldg 270, Detroit Arsenal, MI - 0.17 cfm/sq ft @ 75Pa

Figure 4. 5-5 ADA COF, Joint Base Lewis McChord, WA - Admin- 0.06 cfm/sq ft @ 75Pa Mezzanine Office- 0.19 cfm/sq ft @ 75Pa

Figure 5. Brigade Complex HQ, Joint Base Lewis McChord, WA - 0.05 cfm/sq ft @ 75Pa

Figure 6. School Age Services Center, Ft. Wainwright, AK - 0.16 cfm/sq ft @ 75Pa

Figure 7. Range Control Tower, Ft. Dix, NJ – 0.22 cfm/sq ft @ 75Pa

Figure 8. IBCT UEPH Barracks, Ft. Bliss, TX – 0.07 cfm/sq ft @ 75Pa

Figure 9. SOF Barracks, Ft. Bragg, NC – 0.12 cfm/sq ft @ 75Pa

Figure 10. VOLAR Barracks Renovation, Ft. Polk, LA – 0.14 cfm/sq ft @ 75Pa

3. **Construction and Materials**. The industry was concerned that the new requirement would dictate the use of certain construction types or materials and assemblies, which would close the market to others. While certain materials have become more heavily used due to this requirement, the study shows that there were a number of successful solutions that incorporated combinations of wall and roof air barrier materials. Analysis of specific construction and material types is ongoing and will be presented in a subsequent paper. Table 4 lists the wall and roof/lid materials reported to be used in the study.

Construction Types	Wall Air Barrier Types	Roof/Lid Air Barrier Types
Wood or metal framed	Liquid applied	Self-adhered roof underlayment
PEMB	Building wrap	Single-ply, fully adhered
Concrete tilt, panels, cast	Concrete tilt, panels, cast	Polyethylene sheet
Concrete masonry unit	Interior drywall	Blanket insulation w/scrim sheet
	Spray polyurethane foam	Single-ply, mechanically attached
	XPS board system	Spray polyurethane foam
	Self-adhered membrane	Built-up roof
	Polyethylene sheet	Interior drywall
		Concrete panel, tee, or poured deck

Table 4. Construction and material types use for building envelope sealing .

4. **Holistic Envelope Consulting**. Beyond any other variable that affected the final outcome of the testing was the level of involvement of an envelope or air barrier consultant on the project. A significant difference was noted when an envelope consultant was brought on early in the project and provided consultation in design phase, construction phase, and testing phase as opposed to just testing phase. Figure 11 shows a comparison by building type of buildings that incorporated holistic envelope consulting and projects that did not. Only building types that had at least 10 samples were included in the graph. Buildings compared are Barracks (B), Company Operations Facilities (C), Mezzanine Offices in high bays (MEZ), Tactical Equipment Maintenance Facilities (T), Headquarter Buildings (HQ), Army Reserve Training Centers (RTC), and Other (O), which includes Fitness Centers, Firing Ranges, etc. Data shown in Figure 11 indicate that the use of an envelope consultant improves the performance of the building in all cases.

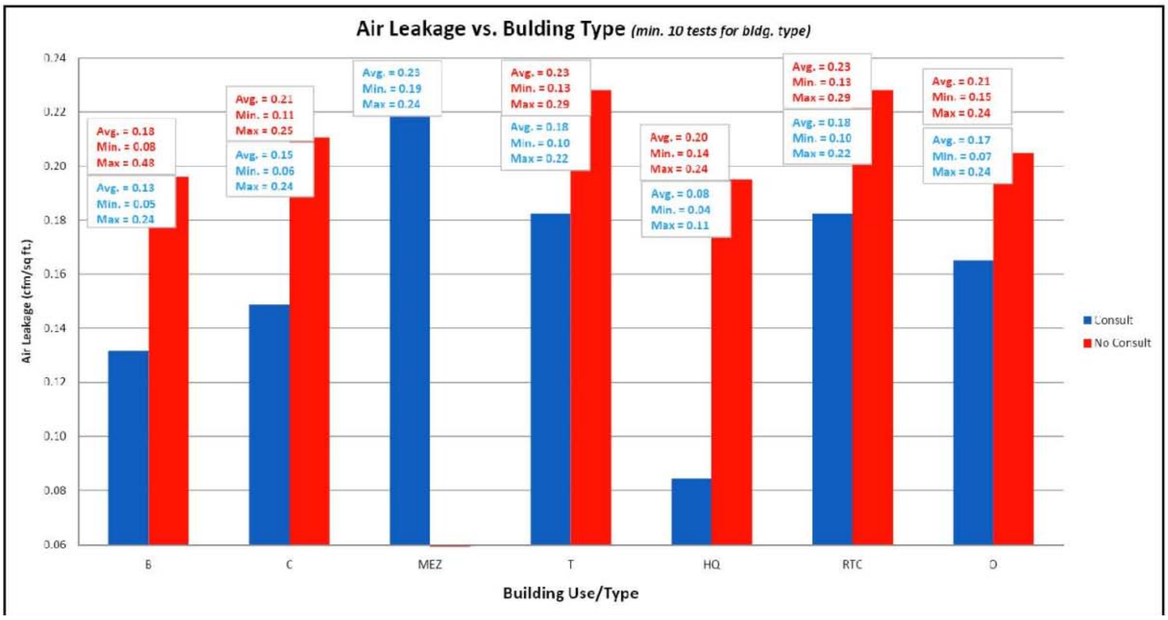

Figure 11. Summary of air leakage test results of 200 buildings by a building type.

SUMMARY

Air barriers play an important role in building durability and energy use and to date have been poorly integrated in the design and construction industry in the United States. With the implementation of the USACE air leakage requirement that include whole building performance verification testing, the industry answered the call. Given the results to date, USACE will be tightening the air leakage rate allowed on DoD projects.

Already several Requests for Proposal (RFPs) have been issued with the new requirement of 0.15 cfm/sq ft @ 75Pa. However, it is recommended that envelopes under 15,000 sq ft remain at the 0.25 cfm/sq ft level. This is due to the fact that when an envelope is this small much of the air leakage that will occur will be in doors and windows that make up a large portion of the smaller envelope. This new requirement will call for a careful design and diligence in the results of the first 200 tests show an average of 0.17 cfm/sq ft @ 75Pa, which is not a significant change from what is already occurring. The data also shows the importance of including an experienced building envelope consultant on the project and RFPs and project specifications have already begun including requirements for a independent envelope consultant to review drawings and perform site visits for quality control review.

The USACE requirement for air tightness already significantly contributes to more durable buildings that consume less energy to operate. The requirement has proven to be both achievable and applicable to all building types and locations. Furthermore, it does not limit the design and construction process to any one set of materials or systems. The move toward tighter buildings will continue, beginning with the USACE tightening the requirement to 0.15 cfm/sq ft @ 75Pa. Based on the data presented in this paper, these results are clearly already achievable.

REFERENCES

[1] Anis, W. (2001). The Impact of Airtightness on System Design. ASHRAE Journal, 43:12. Atlanta, GA: ASHRAE.

[2] ASHRAE. (2009). Handbook of Fundamentals, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

[3] ASHRAE. (2007). Energy Standard for Buildings Except Low-Rise Residential Buildings. ASHRAE Standard 90.1. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

[4] American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE). 2009. Standard for Design of High-Performance Green Buildings. ANSI/ASHRAE/USGBC/IES Standard 189.1-2009. Atlanta, GA: ASHRAE.

[5] ASTM. (2003). E779-03. Standard Test Method for Determining Air Leakage Rate by Fan Pressurization. American Society for Testing and Materials.

[6] Benne, K. and Deru, M. (February 2009). Reference Barracks Building. National Renewable Energy Laboratory, Golden, CO, in preparation.

[7] Canada Mortgage and Housing Corporation. (2002). Monitored Performance of an Innovative Multi-Unit Residential Building. Canada Mortgage and Housing Corporation Research Highlight.

[8] CGSB. (1996). CAN/CGSB-149.15-96. Determination of the Overall Envelope Airtightness of Buildings by the Fan Depressurization Method Using the Building's Air Handling Systems. Canadian General Standards Board.

[9] CIBSE. (2000). Technical Memoranda TM23:2000. Testing Buildings for Air Leakage. Chartered Institution of Building Services Engineers.

[10] Genge, Collin. April 2009. Controlling Air Leakage in Tall Buildings. ASHRAE Journal, pp 50-60. Atlanta, GA: ASHRAE.

[11] Deru, M. and K. Benne. (March 2008). Barracks Energy Conservation Measure: Building Air Tightness. NREL.

[12] Deru, M., K. Benne, and D. Studier. Energy Conservation Measure Analysis: Barracks Building Summary Report. IEA ECBCS Program. Annex 46, www.annex46.org

[13] ECB. Building Air Tightness Requirements. Engineering and Construction Bulletin. ECB 29-2009. US Army Corps of Engineers. 30 October 2009. http://www.wbdg.org/ccb/ARMYCOE/COEECB/ARCHIVES/ecb_2009_29.pdf

[14] ECB 2010-14. Improving Building Performance Through Enhanced Requirements for Energy Performance and Select LEED Credits. http://www.wbdg.org/ccb/ARMYCOE/COEECB/ecb_2010_14.pdf

[15] EPACT 2005. The Energy Policy Act of 2005. http://www1.eere.energy.gov/femp/pdfs/epact_2005.pdf

[16] EISA 2007. The Energy Independence and Security Act of 2007. http://www.gpo.gov/fdsys/pkg/PLAW-110publ140/pdf/PLAW-110publ140.pdf

[17] Energy Conservatory, The. (February 2004). Minneapolis Blower Door™ Operation Manual for Model 3 and Model 4 Systems. The Energy Conservatory.

[18] Genge, Collin. (April 2009). Controlling Air Leakage in Tall Buildings. ASHRAE Journal, pp 50-60.

[19] ISO. (1996). Standard 9972. Thermal Insulation – Determination of Building Airtightness – Fan Pressurization Method. International Standards Organization.

[20] Persily, A. K. (1998). Airtightness of Commercial and Institutional Buildings, Proceedings of ASHRAE Thermal Envelopes VII Conference.

[21] US Department of Energy (DOE). (2007). Energy Plus 3.0. (software program). http://apps1.eere.energy.gov/buildings/energyplus/cfm/reg_form.cfm

[22] US Army Corps of Engineers Air Leakage Test Protocol for Building Envelopes. USACE-ABAA. V.3.0 www.wbdg.org/pdfs/usace_airleakagetestprotocol.pdf
[23] Energy and Process Assessment Protocol. (2009) International Energy Agency, Energy Conservation in Buildings and Community Systems Annex 46.
[24] Zhivov Alexander, David Bailey, Dale Herron, Don Dittus, Michael Deru, and Colin Genge. (2009) Testing and Analyzing US Army Buildings Air Leakage. Proceedings of the 30th AIVC Conference . Trends in High Performance Buildings and the role of Ventilation" and the 4th International Symposium on Building and Ductwork Air Tightness (BUILDAIR). P. 285. Berlin, Germany. October 1-2, 2009. http://toc.proceedings.com/11542webtoc.pdf

Tables 5 and 6 summarize of concerns and lessons learnt regarding reliable airtightness testing and reporting in the United States, and the potential for improving airtightness through QM approaches.

SUMMARY TABLE FOR RELIABLE TESTING AND REPORTING - PREPARED BY THE AIR BARRIER ASSOCIATION OF AMERICA (ABAA)

Questions	Answer
Is there a quality framework for airtightness testers in your country?	The Air Barrier Association of America (ABAA) (http://www.airbarrier.org/)is in the process of developing a certification program for people who will be conducting whole building air tightness testing. As part of this effort ABAA organized a committee for whole building testing and a tester certification program committee in 2010. The committees include testing agencies, air barrier manufacturers, enclosure consultants, all three North American fan test equipment manufacturers and building researchers. At the request of the Army Corps of Engineers the ABAA test committee has revised the US Army Corps of Engineers (ACE) Air Leakage Test Protocol for Building Envelopes http://www.wbdg.org/pdfs/usace_airleakagetestprotocol.pdf. Initially the ACE protocol forms the basis of testing. The ACE protocol references ASTM E779 as the basis for testing but has incorporated additional requirements to address issues that arise while testing larger, more complex buildings. Currently the ABAA committee is developing a standard method for testing building enclosures of all sizes and uses to determine whether they have met specified air tightness requirements. The ABAA certification program for building enclosure fan pressurization testing is being developed to train, test and monitor testing competency based on the standard test methods developed by the test committee.
If yes,	There are multiple reasons for developing the certification program and associated test standards: As airtightness requirements become more frequent in the design and renovation of non-residential buildings qualified testing agencies will be needed to reliably and defensibly conduct building enclosure pressure tests. A number of issues are either not covered by current US test standards or must be further clarified in order to reliably pressure test buildings that are large, complex, extremely leaky or extremely airtight. When pressure testing to determine whether or not a building meets an air tightness requirement these issues become paramount. The ACE test protocol and the new standard test method under development by ABAA elaborate on these issues.
What were the reasons behind the development of these frameworks?	The reason for developing a certification program is to develop a standard set of knowledge, skills and abilities (KSAs) base that all people conducting these tests shall possess in order to assure accuracy, repeatability and reproducibility of the testing. The certification program is planned to include training and written examinations. Certification will follow the completion of the training course and successful completion of test requirements.
What is (are) the body(ies) that issue the certification or qualification?	Building Professionals Quality Institute (BPQI) will be the body that issues the certification.

Questions	Answer
Are there specific guidelines for performing or reporting the airtightness test beyond the requirements of EN 13829 or ISO 9972?	Yes. The details depends on whether one is comparing the ACE protocol to ISO 9972 - 2006 (A2009) or whether one is comparing the test method under development by the ABAA test committee to the proposed ISO 9972. Some of the issues being addressed in the proposed ISO 9972 have been addressed in the ACE protocol and most are being addressed in the standard test method being developed by the ABAA test committee. These issues include: Target airtightness requirements Location and dimensions of the test enclosure boundaries The purpose of the test Logistics for planning and executing a test in buildings occupied by multiple, independent tenants, none of whom may manage or own the building; some of whom may have security requirements that prohibit open, single zones to be established. Test status of HVAC and combustion equipment related penetrations (e.g. motorized dampers closed or closed and air sealed; gravity dampers closed-but-operational, closed and wedged or air sealed; unvented vents or chimneys open or air sealed) Treatment of ancillary spaces (e.g. vented crawlspaces, attached garages, mechanical rooms) Treatment of spaces with interior doors that must remained closed for security purposes Apparatus requirements Data analysis
Are there specific guidelines for the airtightness equipment and software beyond the EN or ISO standards requirements?	Yes. From the currently applicable standard (ACE protocol): Manometer requirements: Digital required Resolution – 0.1 pascal Accuracy - ± 1% or ± 0.25 pascals (whichever is greater) Range -250 to +250 pascals Adjustable averaging of intervals required Calibrated within 2 years or manufacturers recommendations (whichever is the shorter time period). Calibration performed against NIST traceable standards over at least 16 pressures from -250 to +250 pascals Certificates required. Test Fan Measurement requirements: Fans must be calibrated at least every four years in compliance with ASTM E1258 – 88(2008). Calibrated over a range of flows and back pressures including at least the maximum and minimum flows allowed by fan manufacturer plus one intermediate flow and back pressures of 25, 50 and 75 pascals for each back pressure. Calibration certificates must show all data. Accuracy – calibration curve must be within ±5% of each actual test flow Digital manometers and fans may be calibrated separately and used interchangeably
What are the steps for a tester to be qualified/certified?	Obtain the required knowledge, skills and abilities as identified by a job task analysis Meet the pre-qualifications established by the certification scheme Successfully complete the test instruments Complete the required documentation A Certification Scheme Committee (CSC) has been established in accordance with ISO 17024. The CSC is in the process of established the details for the above listed steps.
How many testers are qualified according to this framework?	No testers are currently qualified by the ABAA certification program as the training and testing requirements have not been developed.
Is/are there a specific scheme(s) for airtightness test reporting?	Yes. The ACE protocol (the currently applicable standard) clearly requires specific information in a format included as part of the protocol. The standard test method being developed by the ABAA test committee will also include reporting requirements.

Questions	Answer
If yes,	
What were the reasons behind the development of these schemes?	The specific format is to document competent conduct of the test and accuracy of the final test result including: • all factors relevant to interpreting the test result (e.g. weather conditions, status of HVAC and combustion equipment, single zone condition), • the test data, • analysis of results (e.g. pass/fail, reduction of air leakage rate, acceptable confidence intervals)
Does it include specific measures to guarantee the accuracy of the airtightness inputs in the EP calculation?	The main purpose of the ACE protocol is to determine whether or not a building enclosure is equal to or less than 0.25 cfm/sq ft of enclosure at an induced pressure difference of 75 pascals. It is not intended to produce data that will serve as inputs to energy use models. The standard test method being developed by the ABAA test committee is being developed for the same quality assurance purposes. The intentions are to eliminate building enclosure failures related to infiltrating or exfiltrating air and to reduce fuel and electric power used to condition the buildings. These goals are best achieved using a test that has the smallest confidence intervals at the reference test pressure. While data from the test can be used to provide air leakage inputs for energy models it will not have been collected to reduce uncertainty at fairly small indoor-outdoor pressure differences. More importantly, a single zone condition pressure test provides an unrealistic data set for modeling the energy use of a complex, multizone building in which a network of air pressure relationships are intentionally and accidentally induced by the mechanical system, air density differentials and wind.
Does it include the collection of test reports by a central body?	Currently test results are reported to the Army Corps of Engineers. Data collection programs for tests conducted outside the ACE program is being considered by ABAA.
Is there a monitoring scheme?	As part of the certification scheme, there will be monitoring / surveillance

Questions	Answer
List information and references (preferably in English) on this subject in your country	There are many references. The following are mostly institutional sources. ASHRAE (2009) Handbook of Fundamentals, American Society of Heating, Refrigerating and Air-Conditioning, Inc ASTM. (2010). E779-10. Standard Test Method for Determining Air Leakage Rate by Fan Pressurization. American Society for Testing and Materials. ASTM E 2178 (2003) Standard Test Method for Air Permeance of Building Materials ASTM E 1827 (2011) Standard Test Methods for Determining Air tightness of Buildings Using an Orifice Blower Door ASTM E 1186 (2003; R2009) Standard Practices for Air Leakage Site Detection in Building Envelopes and Air Barrier Systems CGSB. (1986). CAN/CGSB-149.10-86. Determination of the Overall Envelope Air tightness of Buildings by the Fan Depressurization Method. Canadian General Standards Board. CGSB. (1996). CAN/CGSB-149.15-96. Determination of the Overall Envelope Air tightness of Buildings by the Fan Depressurization Method Using the Building's Air Handling Systems. Canadian General Standards Board. ECB. Building Air Tightness Requirements. Engineering and Construction Bulletin. ECB 29-2009. US Army Corps of Engineers. 30 October 2009. http://www.wbdg.org/ccb/ARMYCOE/COEECB/ARCHIVES/ecb_2009_29.pdf ISO. (1996). Standard 9972. Thermal Insulation – Determination of Building Airtightness – Fan Pressurization Method. International Standards Organization. Persily, A. K. (1998). Airtightness of Commercial and Institutional Buildings, Proceedings of ASHRAE Thermal Envelopes VII Conference. US Army Corps of Engineers Air Leakage Test Protocol for Building Envelopes. USACE-ABAA. V.3.0 www.wbdg.org/pdfs/usace_airleakagetestprotocol.pdf Zhivov Alexander, David Bailey, Dale Herron, Don Dittus, Michael Deru, and Colin Genge. (2009) Testing and Analyzing US Army Buildings Air Leakage. Proceedings of the 30th AIVC Conference , Trends in High Performance Buildings and the role of Ventilation" and the 4th International Symposium on Building and Ductwork Air Tightness (BUILDAIR). Berlin, Germany. October 1-2, 2009.

Table 5. Summary of concerns and lessons learnt regarding reliable airtightness testing and reporting in the USA.

SUMMARY TABLE FOR QM APPROACHES

Questions	Answer
What are the benefits for builders or owners for implementing QM approaches?	To ensure that the building enclosure does not fail as a result of air flow through assemblies that results in: • condensation, freeze-thaw, ice dams, efflorescence and sub-fluorescence, corrosion, colonization by pest species (mold, decay fungi, rodents, bats, insects • thermal comfort problems for occupants • excessive energy use for conditioning the interior space.
Are there in your country companies involved in QM approaches for airtightness in the construction process?	Yes. The Air Barrier Association of America has a certification program for contractors that requires implementation of the ABAA Quality Assurance Program. In addition many ABAA members provide services that include: • enclosure design • design review • field inspections • qualitative and quantitative testing during construction • final enclosure testing • forensic investigation of failed enclosures

Questions	Answer
Are there incentives for these QM approaches?	Yes. One accrues to all buildings constructed with QM procedures: reduced building enclosure problems. Others are related to specific programs (E.g. Army Corps of Engineers ECB 2012, GSA P100, EPA EnergyStar, US Green Building Council LEED for Homes, passiv haus, 1000 Home Challenge…)
If yes,	
Are there restrictions?	Yes. The building type must be within the scope of the program (e.g. EnergyStar is limited to singles and multifamily residential buildings).
How are they approved?	The approval process varies from group to group. Most require whole building testing by independent test agencies. In the residential programs testing must be conducted by third parties certified by RESNET or BPI. Some programs allow sampling a fraction of completed projects.
How are they controlled?	
Do you think such approaches have great/moderate/little potential for improving airtightness in practice?	Great potential. I have witnessed a large, general improvement in airtightness and consequent reduction of enclosure problems in residential construction over the past 30 years. Over the same time period the improvement in commercial buildings I have witnessed has been limited to those designed or built by interested, pioneering firms and owners. The Army Corps of Engineers program has resulted in astonishing improvements in building airtightness over the last 3 years. I believe that this improvement would not have occurred without programs that require design review, field inspection and intermediate testing and final testing of building enclosures.
Do you think such approaches give greater confidence in the final airtightness? Has this been evaluated?	Yes. The improvement has been very well documented by the Army Corps of Engineers program.
To your opinion, what are the pitfalls to avoid?	The main pitfall is depending on a final test rather than a process. The details must be in the design and specifications, daily inspections during construction are critical, intermediate third party inspection testing catches many potential errors, final testing provides motivation.
What is your general feeling about these approaches?	I feel good about them. They are already making a difference in the quality and durability of the buildings I see.
List information and references (preferably in English) on this subject in your country	

Table 6. Summary of potential for improving airtightness through QM approaches.

FROM THE DRAWING TABLE TO THE IMPLEMENTATION OF APPROPRIATE CONSTRUCTION DETAILS ON SITE

Mario Bodem Architecte DPLG

ING+ARCH Partnership
Steinstrasse 21
D-90419 Nuernberg, Germany
mario.bodem@ingplusarch.eu

KEYWORDS

Airtightness in passive house; blower door test description in the Tender; visual quality control; timing the airtightness; raising awareness of the planners; airtightness by accident.

INTRODUCTION

The following paper only represents the author’s personal opinion based on 15 years for experience with passive house technology in the German building sector and teaching passive house planers.
The construction sector in Germany is dominated by small and medium size companies, all specialized in their very narrow field. The presence of a general construction company is much less common than in most other European counties. The architect’s task is also a bit different than in most other counties. The architect is by education an architect – engineer who is also the author of the technical detail planning and responsible of the technical site control including the coordination of all specialists and companies.
The architect has to deal with around 10 – 20 different specialized companies on the site. He has to write 10 – 20 very detailed, different tenders and coordinate the timing of these 10-20 companies. So the following conclusions may differ from the practice and experience in other countries with a different construction environment.

AIR TIGHTNESS ACHIEVED “BY ACCIDENT”

Wow do we achieve airtightness in a traditional building process: (provocative answer :)
<<By accident!>>
Which is the company is responsible for the airtightness? Quite a lot of them (German construction sector) but do they know about it?
For example, historically the interior plaster had a basically aesthetical function. It had to create a pleasant surface on the inside of the external wall. Airtightness was not a primary issue, and so was the training of the workers.
The plaster was only applied where it was visible. The areas below the screeds were not treated with the same caution, or not even at all. The same happened to wall areas behind the pipework or in the installation shafts

So one of the very important steps toward achieving better airtightness in the construction process is to raise the awareness of the companies of their new task - but it is not the first step.

DEFINITION OF THE AIRTIGHT LAYERS BY THE PLANER

In a wooden roof construction for example, the air tight layer could be the inside wall paper (not recommended, but often the case). It can be the inside plaster board, or an OSB board in the construction, or a PE vapour barrier. It can also be the wind tight layer on the outside of the insulation or another layer in the construction. The workers, even if they are aware of the importance of airtightness, can only build an airtight connection to the neighbour element (wall, Window etc.) if they know which one of all the possible layers is defined as the airtight layer.
So the very first step is to define the airtight layer!

DESIGNING THE AIRTIGHTNESS

Airtightness has to be planned in the designing process; otherwise we will achieve the traditional “airtightness by chance”. It cannot be improvised on the site. !!
It has to be planed from the very beginning.

Designing it

The intersection of a ventilation pipe placed at a distance of two centimetres from the wall with the airtight layer of the roof is almost impossible to be done in an airtight way. It is not the execution company’s fault, it is a design error.
Practical rule: If there is space for a hand, it can be done.

Describing it

The airtight layer should be named that way explicitly in every drawing. Only then the connection the next element can be designed correctly. Also the connection should be named and labelled “airtight connection to….” in the execution drawings. It is a good self-control element for the designers and as helpful for the tender descriptions as for the building process.

TIMING AND ITS CONSEQUENCES

A very important, but underestimated aspect is the timing in an airtight construction process. Timing cannot be improvised on the site. The time schedule is part of the design process and the timing of an airtight building is lightly different. The following aspects should be considered in the tender descriptions or the contract content:

Different timing and presence

The fact that the timing is different does not mean that is unpredictable. The schedule has to be adapted to the demands of an airtight construction. This difference to a usual site timetable should be mentioned explicitly in the tender description. This can save a lot of money and unnecessary discussions (different orders; supplementary or earlier presence on the site etc.)

Presence at the first blower door test

The companies involved in the airtightness (window, plaster, electrician ect....) absolutely should be present at the first blower door test with at least one person (worker) or better two. These should be the persons who participated in the work process and are capable to do the necessary improvements immediately during the test. Otherwise there will be endless and uncontrollable lists of left over tasks.
The learning aspect is often underestimated. It is a very rare event for a worker that he can see an objectively measured result of the quality of his work. If the result is good it encourages him to continue in the same way or even motivates him to eliminate the remaining leakages. If the result is not satisfying, the nature of the errors can be defined, located, discussed and the learning effect is enormous. Next time he will do it better! Errors do not occur by purpose but mostly by not knowing better.

It should be clearly described that the presence during the blower door test is included in the offer just like the necessary improvements (working time, waiting time and materials).

The aimed result value should also be defined. It is recommended to aim higher than the directives demand.
(n_{50} min. 0.6 1/h for a passive house; we usually demand 0.4 1/h, but try to achieve 0.3 1/h)

A phrase like: ”If the defined N_{50} value will not be achieved, the necessary measures have to be taken by the company to improve the airiness to the defined level on their own costs. The expenses for the necessary supplementary pressure test will also be covered by the company” can help.
It may not always be possible to proof which company is responsible for missing the desired result, but it underlines the importance attributed to the level of airtightness. It also gives the site manger a better position for the unavoidable discussions. Sometimes it just helps to set things clear and avoids a lot of problems.

Working in the right order

Usually the plastering company appears relatively late on the site. At that time often the pipework for the incoming installation like electricity, gas, telephone, water is already mounted. When the first pipes are fixed on the external walls it is too late to put the airtight plaster behind it. If the plaster company is not on the site yet (which is the case most of time) the problem can only be solved with a lot of trouble for the site manager and some extra expenses on one or another side. But the problem is foreseeable. The site manager should be prepared to need some m² of plaster despite of the traditional order.
It could be foreseen in the tender for the plaster company to appear on the site for some square meters before the main work starts, or have some other company that is already on the site has the necessary square meters in their contract. If it is already in the contract it can save a lot of nerves and money for al participants.

Picture 1: Electricity, telephone and water comes early. Be prepared !

Picture 2: Timing - After the installation of the pipework airtight plastering is impossible

Timing the first blower door test

The second timing issue is to define and organize the moment of the first blower door test. When should it take place? The perfect moment would be if all work concerning the airtightness is done but all relevant junctions are still accessible.

This is not easy to accomplish even with a perfect site management. The time schedule has to be organized around this specific event. Some works have to be accelerated, others must be slowed down. Some have to wait until the test to start or to continue their work. This may cause some trouble and extra costs if not foreseen in the timetable from the beginning. Very often the timing issue is underestimated. As most constructions are all the time behind the schedule the timing for the blower door test is ignored to catch up with the schedule.

As a result curial junctions will not be accessible any more when the first test is done. Repair gets more expensive or is impossible.

So the timetable has to be organized around the blower door test and this should be clearly defended and described in the contract or in the written tender documentation.

Picture 3. Controlling the work conditions. In a humid and dusty environment it is impossible to do good work.

Picture 4. Workers present at the test avoid long to-do lists.

Preparing and Organizing the first blower door test

During the construction process it helps to inform and remind the workers that the airtightness will be controlled and measured. Usually the workers on the site are not aware of the content of the tender description.

Regular visual control events, like controlling the first mounted window should be arranged. These events, in presence of, the site manager, the company owner or a responsible controller, the designing architect, and the workers, helps to find errors in an early state. One window is easy to correct. Closer to the end the resistance to modify something will grow. This event also stresses the importance and the attention attributed to air tightness. A very important function of these events is just to draw the attention toward this aspect. The practice has shown – it works!

At these events the working conditions should also be examined. The achieved airtightness depends highly on well prepared surfaces. Dry and dust free conditions are crucial but hardly ever achievable on a construction site. If necessary the firms must be instructed to improve the conditions for example by installing dehumidifiers or by making some extra cleaning efforts.

Aiming high

The German energy efficiency directive demands an n_{50} < 3.0 1/h for buildings without a ventilation system. For buildings with ventilation systems it is supposed to be < 1.5 1/h.
For a passive house n_{50} should meet 0.6 1/h
In our practice we usually achieve a value around 0.3 1/h for small buildings and even much better values (down to 0.07 1/h) in very large buildings. So it is possible to be ten times more airtight than the current directive demands for ordinary buildings. Try to aim high.
Improving from good airtightness to very good airtightness is one of the cheapest means to improve the energy efficiency of a building (with a ventilation system and heat recovery). It is just a matter of quality control and demands no further invest.

CONCLUSION

Training planners, architects and site managers to contribute the necessary attention to airtightness is extremely important. The existing international “Certified Passive House Planner Course” is a good example of a course treating this subject intensively. It covers most of the aspects mentions in this paper. But of course it is not the only mean. The fact that it is part of the planers task to be responsible for the airtightness is not yet common among architects. Most planers consider the responsibility on the side of the construction companies.

So it is very important to raise awareness that achieving airtightness is a highly complex process that succeeds only in a constructive partnership of planers and executing companies, with both parts at the same high level of competence.

THE DEVELOPMENT OF QUALITY GUIDELINES IN FINLAND

Timo Kauppinen[*1], Kari Nissinen,[1] Veli Möttönen[1]

1 VTT Technologies and Services for Buildings, Kaitoväylä 1, PO Box 110, FI-90591 Oulu Finland
timo.kauppinen@vtt.fi

ABSTRACT
In this presentation the quality control subjects are considered from the building commissioning point of view. The performance and energy efficiency of a building depends on many factors which are predicated on each other. Emphasizing one factor at the expense of others has the same result than between partial optimization and total optimization. This doesn´t mean that one particular factor - like air tightness – should be avoided.
Some quality improvements have been introduced, from public and private sector. Air tightness is one of the factors one can affect on energy efficiency and on building performance, but there is some reasonable level which could be tried to get. The problem is also the air tightness of existing building stock and also the performance of ventilation systems.

KEYWORDS
Quality Control, Building Performance, Building Commissioning, Energy Efficiency, Air tightness

INTRODUCTION
The quality guidelines are considered in this presentation as the total performance of a building as a background. The "product" of a building is indoor conditions; the main purpose of quality control is that the building performs as designed during the life-cycle, including safety and durability matters.

The performance of buildings must be defined according to owner's requirements or owner´s project requirements (OPR) [1]. That's why the requirements must be set in early stage – including the objectives for indoor air quality, energy efficiency, the space use efficiency, flexibility and other factors – depending on the use of the building; it is question about key performance indicators (KPI). In practice there are limiting conditions, and one cannot know actually the end user and end user's needs in advance. Also the need of flexibility and possible changes in use usually effect on performance requirements. Building commissioning procedure – or similar quality control procedures help to verify the performance of the building and building services. Buildings are planned to maintain the required conditions [2]: Thermal comfort, the rate of air exchange – everything needed to fulfill the needs set by the owner and by the activities, and by occupants. The structure, building envelope and building services like HVAC installations serve that purpose. Also, the structure and the performance of the building must fulfill structural and safety requirements.

It is very important for new buildings, that its requirements are determined appropriately and detailed. In real projects there are limitations which are mainly caused by two factors:

- The customer / customer's representative have not, for one reason or another, determined or set their needs and requirements at an appropriate level.
- The final use / users of the building have not been decided in the pre-design phase (e.g. shopping malls, in which the final type of the business is not fully known at the beginning).

In the latter point we have an example of flexibility, i.e. the building and the building services should be designed in a way that makes changes of use possible in the future. The building code defines the specifications for energy efficiency and indoor air quality; but all quality- and performance related issues cannot be determined in requirements. There are collected general quality requirements in building branch, e.g. General Quality Requirements of HVAC-installations, published by The Building Information Foundation RTS [3]. The equal quality requirements have also been published dealing with construction works. There are quality standards for building sites etc. Guidelines and instructions have also been published for building automation systems, healthy housing and so on. The crucial thing is how to integrate the different systems to perform together and how the final result equals to the goals; also in case of energy efficiency and air tightness as a part of it.

1. BUILDING COMMISSIONING AS A TOOL FOR QUALITY CONTROL

1.1 Background

The potential to impact on the energy performance of a renovated or new building is described in Figure 1. In the pre-design phase, there are the best opportunities and freedom to impact on the final conditions; the costs are not fixed yet. In the use stage, the costs are already realized and there are only very limited possibilities to change the conditions cheaply – only if the decreased performance is caused by improper use.

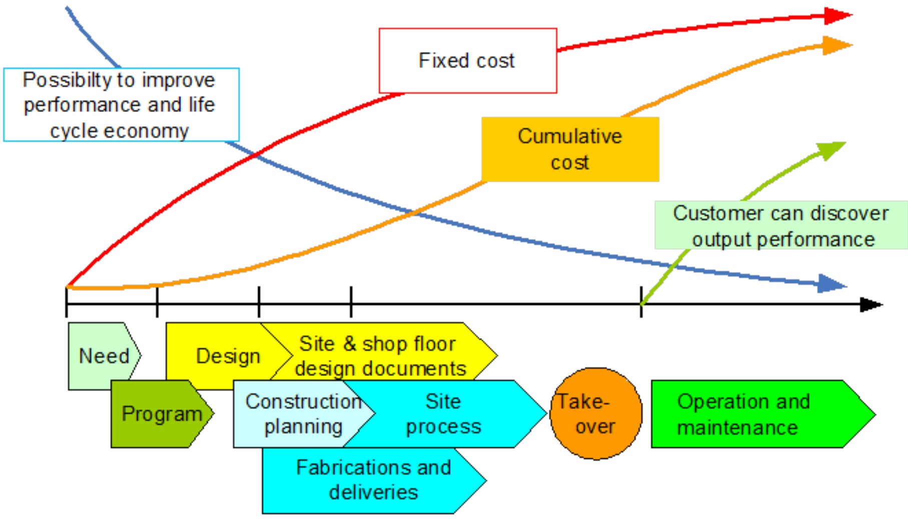

Figure 1. Potential to impact on the energy performance during building process.

The blue curve in figure 1 presents the possibility to improve the performance and life cycle economy. The green curve shows when the occupants/users can observe the defects and malfunctions and defective performance. This green curve shows the amount of reclamations, otherwise than the cost curves. The aim is to minimize the reclamations and to ensure that the performance is as designed.

1.2 Building commissioning (Cx) - procedure

The performance of a building will be determined in many respects during pre-design and the design phase. The crucial issue is that owner's and user's requirements have been defined precisely. By Building Commissioning (Cx) procedure [4] one can verify in the various stages of construction process, that the owner's requirements will be realized (figure 2). At the moment, generally, the technical performance of buildings and building services are verified before operation and use stage – usually during a very short time. Also air tightness will be tested generally in the last stage before the users or occupants are moving in; in worst case only after reclamations. The application of building commissioning procedure in Finland is just in the beginning, it is one tool to verify the total performance of the building, and existing quality control schedules can be implemented in it.

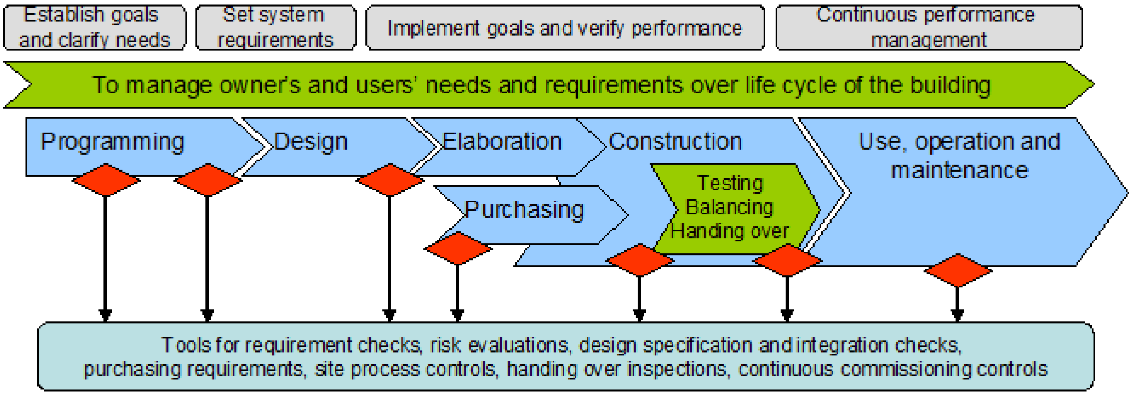

Figure 2. Building commissioning process

First, at the beginning of the renovation or new building project goals are established and requirements are determined. Second, the system requirements are set with the help of design procedures. Third, the goals are implemented and performance is verified in the elaboration and construction phases. Finally, indoor climate and energy consumption is managed with new building automation and online reporting systems. The basic phases (red diamonds 1-7) of the commissioning procedure are described in figure 2.

The installations, instrumentation and automation- and facility management systems should serve to understand the performance of a building. The connection between a facility management system and building automation systems should allow for exploiting the information generated by building automation systems in full scale. Facility management systems should also include the operation and maintenance manual. Commissioning of building automation system should be one of the fundamental operations, because – unfortunately – the performance and even installation details doesn´t match the plans in some cases. Also the malfunction of BAS which effects on energy efficiency, too, is sometimes difficult to detect. If ventilation system is incorrectly balanced (e.g. exhaust air flow >> supplied air flow), pressure difference is increasing and air infiltration is growing if there are leaky points in the building envelope.

1.3 Performance metrics

Before looking at performance evaluation, it is useful to consider how the performance of buildings can be introduced and understood. Performance measurement is one part of the more extensive concepts covering buildings and building services. The performance-related indicators can be formed in many ways, e.g. rating models like LEED for instance. Figure 3 introduces the various factors of indoor environment. Depending on the use of the building, different factors can control the performance – thermal conditions and air quality are the most evaluated topics. Air tightness effects on surface temperatures, air temperatures and air movements.

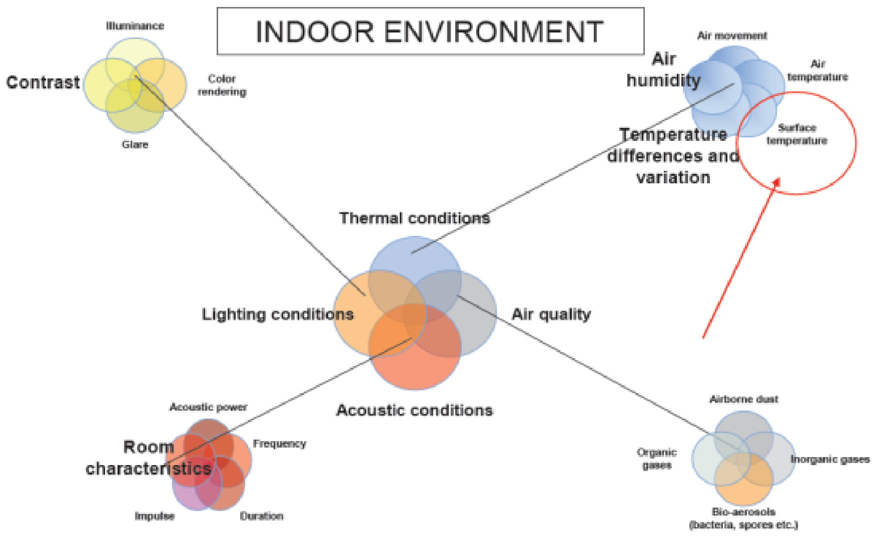

Figure 3. Factors of indoor environment

The metrics currently in use can be separated into performance metrics (direct measurable items, such as occupancy costs and gross floor area) and performance indicators (e.g. how the building is being utilized by measuring data relative to occupancy or floor area). Customer satisfaction is also an important metric and it is typically used as a part of post-occupancy evaluation of a facility. The possible dissatisfaction of the users usually depends on technical performance - which is the sum of various factors – and also on many non-technical issues. In most cases finding out the reason for poor performance requires measurements. The ideal situation would be that existing instrumentation and building automation system could report to the facility manager the recent state of the building.

The commonly used building performance metrics and indicators are:
Metrics related to occupancy costs

- space use
- maintenance and energy costs
- energy and water consumption

Customer satisfaction metrics:

- indoor air quality, i.e. comfort and healthy, temperatures
- cleanliness
- lighting levels

1.4. Indoor environment

Indoor conditions have a great value to productivity. The problem is that the measurement of productivity is extremely difficult in most working communities. The relation between productivity and indoor conditions has been studied -e.g. Seppänen, Tuottava toimisto (Productive office, 2005) [5] - and it have been under large concern (figure 4). According to consistent results achieved in different countries good indoor conditions improve productivity.

According to various studies [6], in knowledge work the labor costs represent about 80 % of all existing costs. The proportion of facility related costs is about 10 % of the total costs). It can be generalized that the share of energy costs is about 3 % of the total costs of a knowledge working organization (in cold climate countries). Saving 10 % of energy means only 0,3% of the total costs. If work efficiency, decreases due to the poor indoor environment, or, because of better indoor conditions, it increases, then, savings and losses are much higher than in the case of energy savings only.

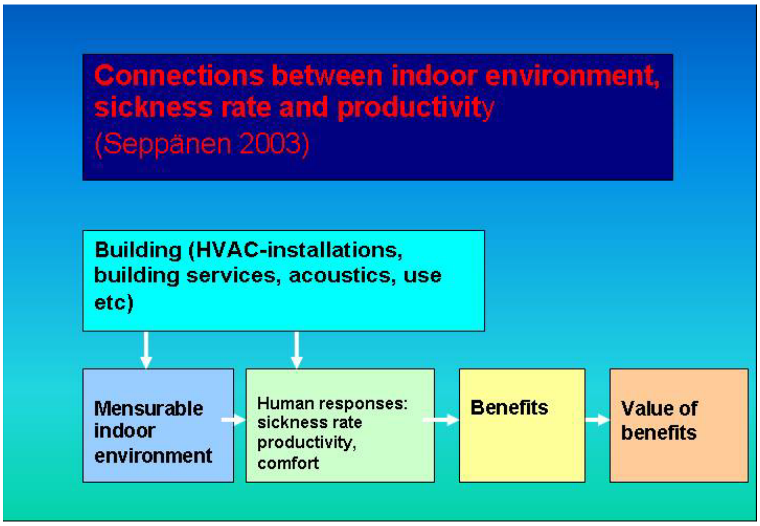

Figure 4. Factors of indoor environment

This has to be seen when building owners have tried to minimize to use of heating energy e.g. by shortening running time of ventilation system. Also the conditions in Nordic countries are totally different compared with Mediterranean conditions.

2. QUALITY CONTROL APPROACHES OF PUBLIC AND PRIVATE SECTOR

2.1. Examples on quality control and air-tightness

Energy Performance Directive caused increasing actions in the building trade. Also the building codes changed. Different professional and educational organizations have launched programs for energy efficiency, quality control and air tightness – even these kinds of events has been also arranged before the latest changes of building codes. Building companies have developed quality assurance programs.

In the next chapter two examples is introduced. One is from the public sector and one from building material industry.

2.2 City of Oulu, Building Supervision Office

More than 30 years ago, the typical air leakage number n50 in one-family houses varied in the level of 6 – 7 1/h (changes/hour). In the turn of millennium the level was 2-3 1/h, but for instance in the city of Oulu the air tightness of new one-family houses has elicited to improve to the level 1 1/h or even below that. The best result since now is 0, 1 1/h, in the target where special attention has paid in air tightness [7].

Every new building in Finland needs building permit given by building supervision office. Almost every municipality (ca. 330) have own building supervision office. Responsibility of the BSOs in Finland is to control, that houses to be built will be carried out according to law, rules and city plan, also taking care of the environment. One task is also to give advices and take care how builders can have better energy efficiency, better sustainability and longer life cycle. The extent of this activity depends on the resources in use. BSO has excellent possibility to give information they conceive important. There has been a “momentum” for quality improvement.

Building permit in Finland includes calculated energy certification, including among others goal of airtightness. Energy certification must be dated before dwellers will move in the house. BSO-Oulu used this “momentum” effectively. The goal for BSO-Oulu is:

- Produce measureable added value to our customers and to City of Oulu,
- help customers,
- To have the courage give advices,
- To have willingness to be co-operative,
- To use public media,
- does R&D work together with designers and builders,
- To create network with local and national actors.

BSO-Oulu has done this work during last ten years and the organization has employed a quality manager too for these tasks. In the year 2010 started a project concerning existing buildings in co-operation of Ministry of Environment. During last ten years BSO-Oulu has arranged together with network of companies many seminars for professionals, designers, public authorities, responsible managers, foremen, builders and families together ca. 10 000 personal training days.

In the year 2008 single-family houses in Oulu were more than 30% more energy-efficient in total average value compared with general regulations in Finland. In bigger dwelling-houses comparable value was over 25% and in other buildings approx. 20%. It is calculated that if the office invests ca. 0, 1 M€, our customers will get back 20 M€ during next 50 year life cycle. In the future this kind results are more difficult (maybe impossible) to achieve, because regulations will tighten/go forward very fast. In Finnish conditions, a change of 1 1/h in air leak value n50 means about 7 % in energy consumption. Good air tightness is one of the most important factors, when constructing very energy efficient or passive houses. Poor air-tightness can cause moisture risks, increase energy consumption and indoor climate is uncomfortable.

2.3 Building material industry - example on building panel manufacturer

A building panel manufacturer has developed a building panel system for industrial buildings logistic centres and warehouses. Air tightness is guarantedd by classify the panels into three categories: Premium, Plus and Basic. The customer options are briefly presented in table 1 and in figure 5.

Premium level: n50 ≤ 0.6 1/h	**Plus level: n50 ≤ 0.9 1/h**	**Basic level: n50 ≤ 1, 3 1/h**
Building envelope: • Envelope area ≥ 8000m2 • Floor area ≥ 3000m2 • Panel area ≥ 1000m2 • Openings ≤ 20%	Building envelope: • Envelope area ≥ 8000m2 • Floor area ≥ 3000m2 • Panel area ≥ 1000m2 • Openings ≤ 20%	Building envelope: • Envelope area ≥ 1600m2 • Openings ≤ 40%

Table 1. Customer´s options for building panels

Figure 4. Customer options of a panel manufacturer

There are also other big companies which have created various programs to increase and guarantee the air tightness of their products or buildings.

3. ENERGY EFFICIENCY AND QUALITY CONTROL

3.1 Examples on energy efficiency and air tightness

There is still lack of measured data dealing with real energy savings vs. air tightness. Figure 5 shows theoretical energy consumption vs. q50 of big buildings according to Finnish energy efficient building code. Coefficient X is 24 and degree day number is = 5000 [9].

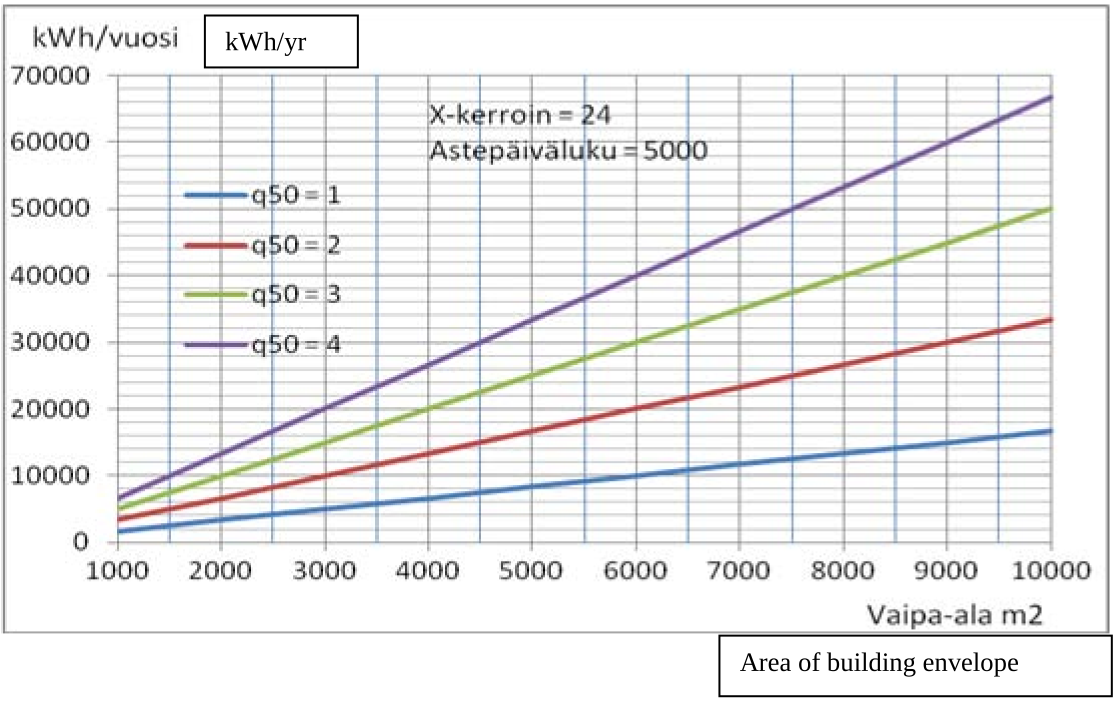

Figure 5. Energy consumption vs. air leak value q50

The air leak value itself doesn't explain the additional heating energy consumption. Air tightness is just one factor of energy efficiency. The normal pressure differences in buildings vary between 0-10…15 Pa (if balancing of ventilation system is properly done). The final performance of the building depends on all effecting factors – and what is most important – how the building systems are integrated to operate together.

The quality of existing building stock is a problem when one tries to improve air tightness of buildings. Without very massive repairs it is impossible to increase air tightness to acceptable level, especially when we are talking about old one-family houses. When we will improve air tightness, we must also take the ventilation into consideration. The more tight building we have, the better ventilation system we must have (which works properly). The phrase "build tight, ventilate right" is continuously valid. In Nordic conditions the buildings are (or should be) depressurized (negative pressure drop) regarding to outdoors. It means that RH of outdoor air will be decreased when air infiltrates through the structures. Penetration of external moisture (rain) causes problems in leaky buildings. It is not only the question about vapor barrier but also about windshield. Insulation layer loses its functionality because of air flows. In natural ventilation systems the upper part of the building is always in overpressure regarding to outdoors. In that case condensation will be a problem.

When ventilation system has been changed from natural ventilation to mechanical ventilation, the old concentrations in external walls have emitted to indoor air, and then the users have appealed the performance of new system, even the actual original reason are leaky structures and old ventilation system.

4. EVALUATION AND CLASSIFICATION OF AIR TIGHTNESS

The following limits have been suggested for air tightness classification (table 2 and figure 6) [8]:

Air tightness rating	
≤0,6	Class A
0,7- 1,0	Class B
1,1- 1,5	Class C
1,6- 2,0	Class D
2,1- 3,0	Class E
3,1- 4,0	Class F
≥4,1	Class G

Table 2. Suggestion for air tightness rating

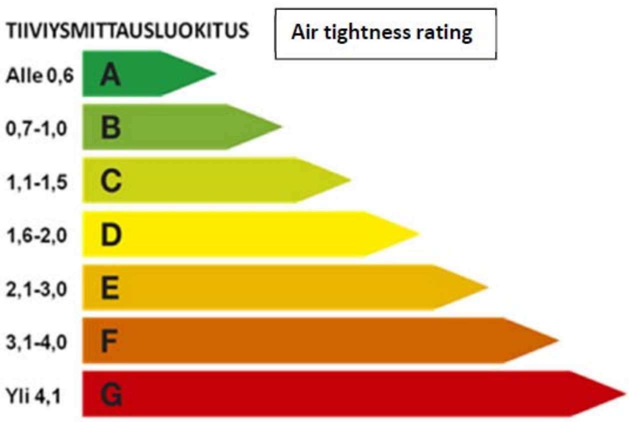

Figure 6. Air tightness labels

This kind of ratings is usable in evaluation of the air tightness, equal to energy labeling. The other question is the tolerance and measurement methods.

CONCLUSION

The building envelope and building services are planned to keep the required conditions, but the outdoor conditions (e.g. fortified by climate change) such as rain, moisture, sun radiation, winds, UV – radiation and temperature variations, especially freezing in cold climate conditions causes aging and deterioration of materials. Also, internal loads affect the durability of materials. Moisture is generally the main cause of defects. Improper use and building defects will accelerate deterioration and shorten the life of the building. Even if the building is properly built; there may be a deficiency in the plans and in use. Wrong materials may have been used, wrong type of architecture design, or the building is a combination of the previous listed factors. In old buildings, which can be historical, too, the design principles may have been different than today and/or the use of the building has changed many times. Usually, the need for renovation is due to reasons other than energy.

In sustainable renovation or new building, the life-cycle costs during the whole life-cycle of the building should be considered. Also the sustainability and environmental impacts must be taken into account to optimize the use of energy, to optimize the environmental load and exposures. This means that in choosing the systems and building components, the total operation and running costs must be taken into account, compared with investment costs.
The running costs control during the expected life-cycle period, compared with the investments costs. Building services (HVAC-installations) now comprise 20 – 40 % of total building costs, so the operation and running costs are very important, the more installations the building contains.

Energy efficiency and air tightness are one part of total building performance. Building commissioning is preferred to ensure and verify the performance of a building. For instance, the energy efficiency of buildings (including air tightness) should be confirmed in all major stages of a construction project: Planning and design stage, implementation, use, operating and maintenance stage. The energy and facility management costs can be optimized by using BEMS (Building Energy Monitoring Systems) and Real Estate Monitoring Systems - type of concepts (if they exist).

In the commissioning concept, all the stages of construction process are considered. At the early stage the owner's and users' needs and requirements, are emphasized and also considered through the whole process. After setting up system goals, implementing the goals (such as air-tightness and what it does mean in practice and in building site) and verifying the performance, indoor climate and energy consumption are managed and monitored as a long term basis for the whole life cycle of the building. The biggest problem at the moment is not lack of instructions and guidelines but integration of different systems to work together, and, how to bring the best practices into the building site. Training is one of the crucial topics in this – starting from vocational schools. Also there may be some wrong attitudes in the field. In recent building projects the tasks has been divided into subcontracts, and the workers may come from various countries of different work cultures and practices. What does actually a big sign ISOsomething in the building site mean?

Dealing with energy efficiency and performance related issues, setting the goals can sometimes be difficult - for instance, the energy consumption only cannot be the goal, but the calculations must be made based on the life cycle costs (the service life, operation and maintenance costs, reliability and interruptions in use and decommissioning). Setting goals is very important at the beginning of a building or renovation project. If there are no detailed targets, it is difficult to follow and verify how the goals have been achieved.

An important question is how to generate a suitable model for a report on operation for the management (and users), which will easily show the most important key figures and factors, at a glance. The displays, especially in schools and in other public buildings would be very effective in increasing common awareness. This will set requirements for instrumentation, monitoring and design.

Air tightness and its effects are part of building physics – do we have knowledge enough about all the factors which must be taken into account?

ACKNOWLEDGEMENTS

Authors have discussed about the content with Mr. Juhani Heljo, Tampere University of Technology and Mr. Markku Hienonen, Building Supervision Office of Oulu. Mr. Sauli Paloniitty, HAMK University of Applied Sciences and Mr. Pasi Turpeenniemi, Ruukki Construction, have given material in the use.

REFERENCES

[1] Karvonen, Iris &al. Towards a Reference Model for Building Lifecycle Performance Measurement Profile Proc. 1st International Conference on Industrialised, Integrated, Intelligent Construction (I3CON). Loughborough University, UK, 14 - 16 May 2008 (2008)
[2] Kauppinen, Timo &al. Performance measurement. Industrialised, Integrated, Intelligent Construction Handbook I. Wallis, I.; Bilan, L.; Smith, M.(eds). I3CON in collaboration with BSRIA (2009), 12 – 27. http://www.i3con.org/files/I3CON-Handbook-1-final.pdf
[3] Talotekniikka RYL 2002. Talotekniikan rakentamisen yleiset laatuvaatimukset. Osat 1 ja 2, General Quality Requirements of HVAC-installations, Part 1 and 2) Publishers: LVI-Keskusliitto ry, Sähkötieto ry, Rakennustietosäätiö RTS. Publisher: Rakennustieto Oy 2003 (in Finnsh) 696 p., LVI 01-10355, LVI 01-10356, ISBN: 951-682-707-1
[4] Pietiläinen, J., &al. ToVa-käsikirja. Rakennuksen toimivuuden varmistaminen energiatehokkuuden ja sisäilmaston kannalta (Building Commissioning in terms of energy efficiency and indoor conditions). Espoo:VTT 2007. (VTT Research Notes).
[5] Seppänen, O (ed). Tuottava toimisto 2005. Loppuraportti, Helsinki University of Technology. Raportti B77. ISBN 951-22-7286-5, ISSN 1455-2043, Vantaa 2004. (Productive office 2005, final report).
[6] Seppänen, O. Sisäympäristön vaikutus tuottavuuteen. Sisäilmastoseminaari. 2006. (SIY Raportti 24/2006). Sisäilmayhdistys 2006. (The effect of indoor environment on productivity. Indoor air seminar 2006, Indoor Air Association of Finland)
[7] http://www.bosti.com. , Bosti Associates.
[8] Hienonen, Markku & al. Improvement of air tightness of communities. Joint Conference 32nd AIVC Conference and 1st TightVent Conference Towards Optimal Airtightness Performance; Brussels, Belgium; Oct 12-13, 2011 (2011)
[9] Paloniitty, Sauli. Rakennusten tiiviyden mittaus (Air tightness measurement of buildings). Manuscript, to be published 2012. Rakennustieto Oy. www.rakennustieto.fi

NEW CONSTRUCTION ENERGY EFFICIENCY PROGRAMS IN THE UNITED STATES – LESSONS LEARNED FROM TWO QUALITY MANAGEMENT PROGRAMS

Jonathan Coulter[1]*, and Benjamin Hannas[1], Colby Swanson[1], Michael Blasnik[2]*, and Eric Calhoun[1]

[1]Advanced Energy
909 Capability Drive Suite 2100
Raleigh, North Carolina, USA
*Email: jcoulter@advancedenergy.org

[2]M. Blasnik & Associates
150 Poplar Street
Roslindale, Massachusetts, USA
*Email: michael.blasnik@verizon.net

ABSTRACT

The objective of this paper is to compare two high performance [1] new construction quality management programs, ENERGY STAR® and Guaranteed Performance homes co-located in Phoenix, Arizona, USA, and determine if homes in these two groups could be distinguished from each other in terms of actual summer/cooling energy usage or homeowner satisfaction related to the HVAC systems compared to Baseline homes. The summer/cooling energy use study surveyed 7,141 houses, of which 3,336 were Baseline homes, 2,979 were ENERGY STAR homes and 826 were Guaranteed Performance homes. The onsite verification process to confirm compliance to both of these above code programs was completed by the same qualified certified expert, a nationally recognized HERS Rater. Statistically valid energy data shows that ENERGY STAR homes saved, on average, 16% in summer/cooling energy use (kWh/m²) as compared to the typical Baseline homes. The Guaranteed Performance homes saved, on average, 33% in summer/cooling energy use over the Baseline homes and saved 20% compared to ENERGY STAR homes. During the spring and summer of 2005, the homeowner satisfaction study was administered to 708 houses from the same 7,141 house sample set. This second study found that 49% of the Guaranteed Performance homeowners said they were completely satisfied with their home's "ability to keep them comfortable year round" compared to 35% of ENERGY STAR homeowners and only 27% of Baseline homeowners. In fact, this survey found that Guaranteed Performance homeowners were more satisfied with every aspect of their home's HVAC performance – year round comfort, the freshness of air inside of the house, evenness of temperatures from room to room, reliability and cooling cost compared to Baseline and ENERGY STAR houses [2]. Combining the results from these two studies shows that the enhanced quality management approach used by the Guaranteed Performance homes program consumes less energy than comparable ENERGY STAR or code-built homes while simultaneously improving homeowner satisfaction.

KEYWORDS

Energy efficiency programs, quality management programs, energy consumption, homeowner satisfaction, guaranteed performance

INTRODUCTION

For more than 30 years, a variety of approaches have been tried in the United States to improve the energy efficiency of newly-constructed homes. Before 2004, millions of homes had been constructed to local building codes, about 400,000 were ENERGY STAR compliant and more than 60,000 qualified for Guaranteed Performance recognition. For all the attention on projected and deemed energy savings these programs were claiming, there was not enough data being analyzed to determine the actual energy reduction impact or homeowner satisfaction these quality management programs were having post-occupancy [2].

Throughout the past several decades, rising energy prices have driven a demand for more energy-efficient homes. Builders initially responded with simple energy saving elements such as increased insulation, double-paned glass, tighter door seals, window awnings and other measures. Recent field applications of building physics advancements (such as high-efficiency HVAC equipment, improved duct sealing, building infiltration barriers, low-e glass and compact fluorescent lighting) along with enhanced quality management approaches have continued to offer more sophisticated and effective methods of providing predicted energy savings. Each of these measures reduces overall home energy bills in computer modeling, but little is known about how these changes effect the homeowners as they live in these homes, or whether overall homeowner satisfaction is being influenced by these building changes. This report summarizes results from two studies to compare local code-built or Baseline, ENERGY STAR and Guaranteed Performance homes and determines if homes in these three groups have different summer/cooling energy usage or homeowner satisfaction. Because the ENERGY STAR and Guaranteed Performance programs have similar building component requirements, this analysis also reveals the successes of the quality management process used in each program.

ENERGY STAR Homes Background

In 1995, the U.S. Environmental Protection Agency (EPA) launched its ENERGY STAR Homes program, which established guidelines for reducing home energy use and promoted partnerships with homebuilders to construct homes more energy efficient than code-built homes. A thesis study of 291 homes in Phoenix, Arizona in 2000 compared ENERGY STAR homes to code-built homes and concluded that ENERGY STAR homes used 2.3% less energy per square foot than code-built homes [3]. At the time the energy use and homeowner satisfaction studies began in 2004, the program standards based on computer modeling proposed savings of 30% for home heating, cooling and water heating as compared to the Baseline homes built to the requirements of the 1993 Model Energy Code (MEC) or 15% more efficient than state energy code, whichever was more rigorous. These ENERGY STAR homes realized these model savings based on guidelines of [4]:

- House envelope infiltration of 5.6 m^3/hr per m^2 of envelope area at 50 Pascals of pressure difference between the house and outside
- HVAC duct leakage of $\leq$ 3 L/s to outdoors per 10 m^2 of conditioned floor area at 25 Pascals of pressure difference between the ducts and outside
- Improved wall, ceiling and floor insulation levels
- Higher U-value for windows and doors
- More efficient HVAC systems

The adherence of these guidelines was field-verified by a Residential Energy Services Network (RESNET)-certified Home Energy Rating System Rater (HERS Rater) using a RESNET-approved testing protocol on a random number of houses. ENERGY STAR certified homes, it was reasoned, would offer homeowners independently-verified dependable savings on their monthly energy bills while collectively reducing the overall energy consumption and impact of the residential sector nationwide; however, factors such as homeowners' lifestyles (with respect to energy use), effective product installations, operation and maintenance of HVAC systems, house sizes and others made it difficult to assess the actual impact these energy efficiency intentions had on lowering home energy usage. Computer-modeled and deemed energy savings were available for the 400,000 plus homes built by 2004 (more than 1.3 million by 2012), but little was known about the post-occupancy energy performance or homeowner comfort of these homes. Or, to look at it another way, was the quality management process utilized in the ENERGY STAR program ensuring measureable energy savings over the code-built homes once the house was lived in?

Guaranteed Performance Homes Background

More recently, several organizations created and promoted an ENERGY STAR "Plus" program for the new construction market. Called Guaranteed Performance homes, these homes are designed and built to go beyond the EPA ENERGY STAR program by:

- Specifying the use of more energy-efficient building components of [5]:
    - House envelope infiltration of 5.6 m^3/hr per m^2 of envelope area (n_{50} 7) at 50 Pascals of pressure difference between the house and outside
    - HVAC duct leakage of $\leq$ 1.5 L/s for total system per 10 m^2 of conditioned floor area at 25 Pascals of pressure difference between the ducts and outside
    - Improved wall, ceiling and floor insulation levels
    - Better (lower) U-value windows and doors
    - More efficient HVAC system
- Requiring trainings on: program standards, building physics, field details the builder, insulator or HVAC contractor is responsible for.
- Mandating100% field quality assurance checks of the houses by the same RESNET-certified HERS Rater using the same RESNET-approved testing protocol after framing, wall insulation and completed construction to ensure the specifications are met at every stage.
- Providing a two-year heating and cooling energy use guarantee to the homeowners (of €1 per day for a typical 190 m^2 house).
- Providing a two-year comfort guarantee to the homeowners (defined as a temperature differential of no greater than plus or minus 2 degrees Celsius (3 degrees Fahrenheit) from the thermostat location to the center of any conditioned room within the zone) to ensure the house is performing as designed after the homeowners have moved in.

Before this study was conducted in 2004, there were more than 60,000 houses nationwide built and certified to the Guaranteed Performance standards. To date in 2012, there are more than 150,000 homes built to these standards.

Training for Certified Experts

For both the ENERGY STAR and Guaranteed Performance programs, certified experts, called HERS Raters, inspect and evaluate a home's energy components and ensure that both the ENERGY STAR program requirements are met for the home as well as the RESNET requirements for data analysis and collection. RESNET sets the national industry standards for the training, testing, certification, ethical conduct and oversight of the HERS Raters. To become a certified HERS Rater, the requirements are to:

1) pass electronic and field based core competency tests on building physics concepts as well as the accurate uses of house and duct leakage testing equipment

2) complete the required probationary ratings with a RESNET-accredited Rating Provider and comply with the yearly electronic and field quality assurance checks of that Rating Provider

This Rating Provider is an oversight organization responsible to RESNET for the quality assurance of each HERS Rater. This entire process from initial training through yearly quality assurance checks is governed by the RESNET Mortgage Industry National Home Energy Rating System Standards.

Quality Assurance Checks

The quality assurance checks in both programs require the completion of electronic software analysis of the construction plans with proposed building components efficiencies before any onsite inspections and performance testing (house and duct leakages) occurs. Through the compliance with the RESNET Mortgage Industry National Home Energy Rating System Standards [6], the HERS Raters are required to collect and assess onsite the installation quality of the minimum rated features of each home before the energy efficiency software file can be completed and checked for compliance with the program standards. Only after the software file verifies the program standards have been met can it be submitted to a Rating Provider for approval and the home be certified as ENERGY STAR. In addition to a software file, in order to receive Guaranteed Performance status, every home must also have a Thermal Bypass Checklist (TBC) completed to confirm the quality of the air and thermal barriers of the house meet program standards.

Reporting Procedures and Oversight of Experts

Once the energy efficiency software file and related TBC confirms adherence to program standards, it can be submitted to the Rating Provider for the issuance of the ENERGY STAR and/or Guaranteed Performance program certifications. Separate from the building meeting program standards, RESNET also requires the Rating Provider to perform annual software and field quality assurance inspections on the HERS Raters work, a minimum of 10% of all electronic files and a minimum of 1% of onsite inspections. Then, a possible third layer of expert oversight comes if the home is in the Guaranteed Performance program. Since this program also includes a post-occupancy heating and cooling energy use and comfort guarantee, the actual utility bills are checked for compliance with program projections and the quality of the expert's involvement.

METHODS

Quality Management Programs

Because the Phoenix, Arizona market was an early adopter of both the ENERGY STAR and Guaranteed Performance programs, there is a high concentration of homes with many years worth of energy use data that provided an excellent opportunity to compare those quality management programs and verify energy consumption data on the three home types under real-world conditions. And since both quality management programs depend on the same trained HERS Raters, the most likely cause for variation in actual home performance should be from program standards and requirements.

Energy Efficiency

For the 7,141 houses included in the energy study, data was compiled and analyzed based on the following three categories: Baseline homes (3,336 homes not built as part of any energy efficiency program, but resembled other homes in the study), ENERGY STAR homes (2,979 homes built per EPA ENERGY STAR program standards) and Guaranteed Performance homes (826 ENERGY STAR homes plus additional energy efficiency improvements, as well as a comfort and heating/cooling use guarantee). Once assigned to a category above, the homes were then segregated by builder, year built, square footage, presence of swimming pool, solar orientation, HVAC type and zip code. These groupings helped identify patterns in the data that can point to factors with the greatest effect on home efficiency within the boundaries of the study [2].

Homeowner Satisfaction Survey

The homeowner satisfaction survey was conducted in Phoenix during the spring and summer of 2005. It was conducted in two phases [7]:

1. Qualitative Research

   The first steps began with qualitative research among homeowners, builders and contractors to understand what drives homeowner satisfaction and to ensure that the survey document was comprehensive and written in the homeowner's language.

2. Quantitative Research

   A written, four-page survey was mailed to 7,000 homeowners during July and August 2005. In all, 708 homeowners responded with completed surveys. A market research firm designed the survey and tabulated the returned surveys with an overall sampling margin of error of 3.7 percentage points at a 95% confidence level.

RESULTS

Figure 1 shows the concentration of house type per year built.

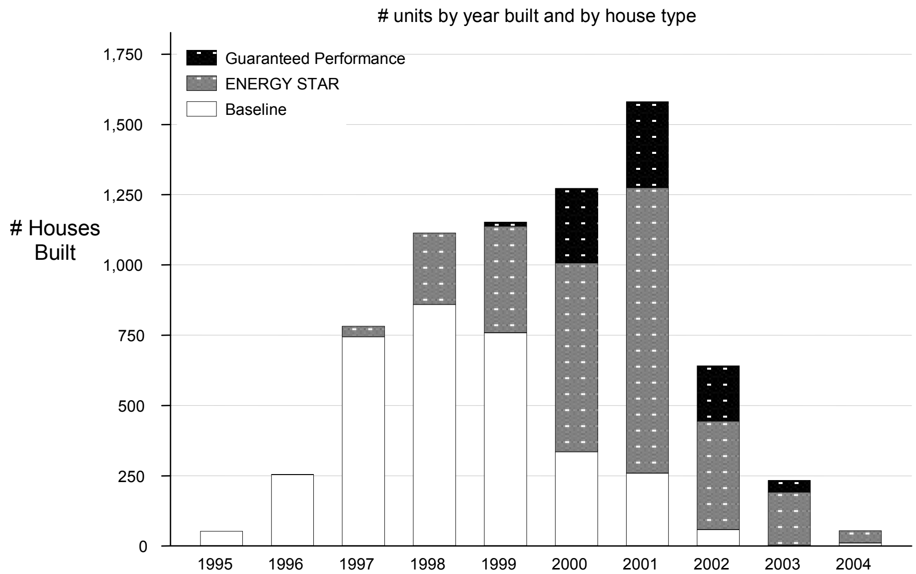

Figure 1: Study Homes by Year Built and Category

Energy Intensity (kWh/m²)

Table 1 outlines the summer/cooling energy use of gas-heated Baseline, ENERGY STAR and Guaranteed Performance homes with no swimming pools. Results are separated by house size into small (< 148 m^2), medium (149-223 m^2) and large (> 223 m^2) homes.

	Baseline	ENERGY STAR	Guaranteed Performance
Homes < 148 m²			
# Homes	282	326	141
kWh/m²/yr	0.41	0.38	0.33
Homes 149-223 m^2			
# Homes	37	660	282
kWh/m²/yr	n/a	0.33	0.25
Homes > 223 m^2			
# Homes	20	208	136
kWh/m²/yr	n/a	0.28	0.21

Table 1: Summer/Cooling Comparison

Energy Savings

After applying regression analysis, the annual summer/cooling intensities were estimated to be 16% lower for ENERGY STAR homes compared to Baseline homes (0.325 kWh/m2 versus 0.386 kWh/m2). Guaranteed Performance homes realized an energy savings of 33% over Baseline homes (0.260 kWh/m2 versus 0.386 kWh/ft2) or roughly 1,800 kWh/year. Of the 708 total responses to the homeowner satisfaction survey, the breakdown is as follows:

- 205 (29%) were from baseline homeowners

- 255 (36%) were from ENERGY STAR homeowners
- 235 (33%) were from Guaranteed Performance homeowners
- 13 (2%) were unknown

Category of Home	Need	Driver of Satisfaction	Guaranteed Performance	ENERGY STAR	Baseline
SUMMER PERFORMANCE DRIVERS FOR ALL HOMEOWNERS	COMFORT	Your ability to regulate temperatures during the summer	41%	28%	23%
		The ability of your home to keep you comfortable during the summer	37%	22%	20%
		The ability of your air conditioner to cool your home quickly	36%	25%	19%
		The evenness of temperatures from room to room during the summer	25%	14%	12%
	ENERGY EFFICIENCY	The cost of cooling your home	22%	14%	12%
	RELIABLE PERFORM-ANCE	The reliability of your cooling system (i.e., repair frequency)	53%	41%	32%
		The noise of your cooling system when it's running	29%	19%	15%

Table 2: Homeowner Satisfaction with Drivers of Satisfaction

One of the key findings in this survey shows that Guaranteed Performance homeowners are more satisfied than ENERGY STAR or Baseline homeowners on almost every one of the following influences or drivers of satisfaction: comfort, energy efficiency, reliable performance, healthiness. Table 2 summarizes the percent of homeowners that are completely satisfied with drivers of satisfaction as well as the statistical relevance of each measure. Each measurement was statistically significant to 99%.

DISCUSSION

At the beginning of this project, there was skepticism around the validity of conducting a study to compare homes across the three categories we selected (Baseline, ENERGY STAR and Guaranteed Performance). The concern was that the amount of variability due to factors that have nothing to do with the programs we were studying or that cannot be controlled, would mask any noticeable differences. However, after having done this study and confirming there is tremendous variability, the sample size was still large enough to see statistically significant differences among the three categories. While we have accumulated a body of evidence which indicates that the programs are a driver of these savings in one specific geographic region, the data should not be viewed as proof for all regions of the U.S. We recognize there are issues, and we cannot prove the exact amount of savings nationwide, but we now have a jumping point for further investigation and benchmarking in other locations. Bottom line – this kind of study can produce valid results and those results will be strengthened with additional data. That being said, the important findings from this study include:

- Given that the same expert certification, RESNET HERS Rater status, is required for both quality management programs, there is strong confidence that the involvement of these professionals did not complicate the data.

- The number of homeowners surveyed was large enough to give statistical reliability, but due to variations in climate, construction practices, etc., these results are not extendable to other markets outside of Phoenix.
- In this cooling dominated climate, homes facing northeast had significantly lower summer/cooling energy use than homes facing east (the default category), but no other orientations showed statistically significant differences.
- This survey demonstrates that right-size HVAC systems, along with other energy efficient features, result in greater homeowner satisfaction.
- The researchers believe there is a latent demand for higher performance, or better building science, on the part of the homeowner. Unfortunately, this demand seems to be overshadowed by other factors at the time of purchase.

CONCLUSION

Implementation of the ENERGY STAR and Guaranteed Performance programs can yield improvements in the overall energy efficiency of new homes, as compared to homes built to code. The quantitative actual energy use results and homeowner satisfaction results from three levels of home construction (Baseline, ENERGY STAR and Guaranteed Performance) demonstrate that when the quality management and energy-efficient building requirements of the ENERGY STAR homes program were followed, the houses used 16% less summer/cooling energy and were 35% more comfortable than Baseline homes. But even more energy savings of 33%, as well as increased overall homeowner satisfaction of 49%, were possible when additional energy efficient requirements, a more systematic approach to quality management, and a two-year comfort/heating/cooling use guarantee were added to the Baseline homes, meeting the Guaranteed Performance homes program standards.

These win-win findings will help the managers of the EPA ENERGY STAR, Guaranteed Performance and other energy-efficient new building programs adjust their respective program guidelines to ensure that the most cost-effective, energy-saving and training-related measures are identified and implemented into new home construction. For code officials, this may provide ideas for future changes. For homebuilders, contractors and other industry professionals, these measured results will provide evidence to support their claims of increased value, profits and energy savings, validate the benefits of commissioning and feedback loops while simultaneously helping expand the market share of energy-efficient homes. Utility services may also benefit from this study by using the data to help identify key parts of successful program design, highlight future trends in the housing market and predict patterns of energy use.

The performance and satisfaction "bar" for new energy-efficient home construction has been raised in the Phoenix area as a result of the ENERGY STAR and Guaranteed Performance home programs. These programs have been instrumental in the education and training of consumers, builders and contractors about the benefits and construction differences of higher performing homes and homes with higher homeowner satisfaction. This study was initiated to provide a model for ongoing efforts to illuminate impact, as well as a feedback mechanism to support continuous improvement of energy-efficient programs for new home construction in the rest of the United States, as well as the world.

ACKNOWLEDGEMENT

U.S. Environmental Protection Agency, U.S. Department of Energy, Arizona Public Service and Southwest Gas should be especially recognized for their support of this study.

REFERENCES

[1] Erhorn-Kluttig, H, Erhorn, H. January 2011. Terms and Definitions For High Performance Buildings.
[2] Swanson, C, Blasnik, M, and Calhoun, E. 2005. Measuring Public Benefit From Energy Efficient Homes. Report submitted to U.S. Environmental Protection Agency by Advanced Energy, Raleigh, NC.
[3] Energy Consumption Comparison of ENERGY STAR® Homes in Phoenix, Arizona, Bradley Jay Bashford, Arizona State University, May 2000.
[4] http://www.energystar.gov/index.cfm?c=bldrs_lenders_raters.nh_v2_guidelines
[5] http://www.environmentsforliving.com/EFLPublicSite/index.jsp
[6] RESNET. 2006 Mortgage Industry National Home Energy Rating Systems Standards.
[7] Dixon, T, Swanson, C, and Heineman, D. 2006. Phoenix Homeowner Satisfaction Survey. Report submitted to U. S. Department of Energy by Advanced Energy, Raleigh, NC.

Initial ideas for achieving reliable airtightness assessment in the Belgian context

Xavier Loncour / Peter Wouters
BBRI, Belgium

A METHOD TO ENSURE AIRTIGHTNESS OF THE BUILDING ENVELOPE

Eva Sikander[1]

1 SP Technical Research Institute of Sweden
Box 857
SE-501 15 Borås, Sweden

ABSTRACT

Several projects have shown the importance of airtightness of buildings in order to ensure efficient energy use, good indoor environments, protection against moisture and general durability.

The purpose of this project has been to develop a method to follow in order to design and construct airtight building envelopes. The method is based on experience from several building projects with the aim of identifying critical design aspects, critical workmanship, critical activities during design and construction and also critical information/education issues. One important factor is ensuring that requirements in respect of airtightness are clearly expressed, combined with follow-up to verify that the requirements have been fulfilled during the design and construction stages. The method can be used of the building developer, designer and/or construction company.

Based on experience from building projects and earlier research in the area of airtightness, this project presents a general method for the design and construction of airtight buildings, covering all aspects from initial formulation of requirements, through general and detailed design, to production and monitoring. The routines and checklists provide a means of applying the knowledge and experience from research and development projects to practical use.

KEYWORDS

Airtightness, building envelope, method, requirements, monitoring, quality management.

INTRODUCTION

There is a need for a method that can be implemented in the building process to achieve airtight buildings. There are experiences from the building process where airtight building envelopes have been reached, and there are also knowledge from research projects that can be communicated to the building industry to assist in the process to ensure airtight building envelopes.

1. OBJECTIVE

The objective of the work of the project is to develop a general method for the construction of airtight buildings, covering formulation/expression of requirements, planning, design and construction. The method is based on quality management/assurance through ongoing documentation, communication, inspection and verification, using quality management procedures and associated checklists. The checklists provide a means of disseminating the results obtained and knowledge acquired for practical application.

The intention is that the method should assist those involved in the building sector, and particularly contractors, to ensure that a building meets the function requirements that have been specified. Properly drawn-up function requirements and quality management of the construction process provide favourable conditions for producing an airtight building.

2. IMPLEMENTATION

The work has been carried out in two stages. Stage 1 developed the quality assurance method, while Stage 2 tested it in a pilot project, with the results being thereafter evaluated. The associated training materials have also been tested in connection with starting a building project. Improvements have been made, based on experience from the pilot projects.

3. METHOD FOR PRODUCING AIRTIGHT BUILDINGS

3.1 Airtightness during early planning stage

Figure 1. Clear formulation of requirements provides the basis for successfully achieving an airtight building. The Lindås houses are an example of such a project, in which requirements were formulated and monitored.

The following procedures are intended to assist developers in their own work of deciding on requirements and monitoring their application in order to arrive at good airtightness:

The developer’s procedure/checklist (can also be used by the developer’s representative):

a) Decide on the required ambition level for the developer’s own work.
b) For conversion/rebuilding projects, perform a survey/inventory.
c) Formulate requirements for an airtight building. This must include both technical requirements and those governing work/activities. See chapter 4.

d) Check/review procurement procedures and contract details in order to be sure that requirements are being correctly understood.
e) Appoint a person to be responsible for monitoring application of requirements and deciding the forms of monitoring.
f) If necessary: arrange information/training for those involved prior to starting work.

3.2 Airtightness during design stage

Figure 2. Penetrations through the sealing membrane can be avoided if the membrane is applied in such a way as to leave a gap for installation of the building's services systems.

The following is a procedure description/checklist to assist the designer's work of achieving airtight buildings, bearing in mind that it is not only this work that is important, but also communication of the necessary information to developers and contractors.

The designer's procedure/checklist for the design stage:

a) Appoint a person to be responsible for matters relating to airtightness during the design stage, with his/her work including this procedure/checklist.
b) Go through the requirements and intentions with the developer, ensuring that all are properly understood and accepted.
c) Provide necessary information/training.
d) Perform the design work and prepare documentation in accordance with checklists.
e) Perform internal checking of design documents in respect of airtightness.
f) Identify, plan and document critical production stages in conjunction with contractors.
g) Handing over to contractors: prepare a plan for airtightness during the production stage in conjunction with contractors.
h) Collect and put together all necessary documentation.

The following is a description of the procedure for the developer's monitoring of the work during the design stage. The developer's involvement is important and helps to maintain quality.

The developer's procedure for monitoring during the design stage:

a) Contact with the person responsible for airtightness aspects, and checking his/her internal communication of requirements, dissemination of information and provision of training.
b) Checking of documentation of materials to be used for air sealing purposes and of proposed designs.

c) Obtain confirmation that the contractor has carefully gone through the design documents.
d) Obtain confirmation, in conjunction with the contractor, that the contractor has identified critical tasks, and that an inspection plan for production/construction has been prepared.

3.3 Airtightness during production stage

Figure 3. An airtightness test (Blower-Door), looking for air leaks, provides indication of whether the requirements have been fulfilled.

The following is a description of the contractor's procedures/checklists for the work of delivering an airtight building, for which the contractor's quality of workmanship is important, as is communication with the designers and the developer.

The contractor's procedure/checklist for the production/construction stage:

a) Appoint a person to be responsible for airtightness-related work aspects at the site.
b) Go through the airtightness requirements.
c) Go through the design documents together with the designers, to discuss critical stages / details of production.
d) If changes are made, show that airtightness requirements will be met after the changes.
e) Draw up an inspection plan in conjunction with the designers.
f) Arrange internal information/training that also includes sub-contractors.
g) Work planning (before each new stage).
h) Preliminary airtightness testing and leak tracing.
i) Final airtightness testing.
j) Feed back information/experience to the designers.

The developer's procedure for monitoring during the construction stage:

a) Contact with the person responsible for matters relating to airtightness and ensuring that he/she is providing all necessary internal communication of requirements, information and training.
b) Ensure that documentation from internal inspections is being prepared in accordance with the overall inspection plans.
c) Check documentation from early airtightness tests/leak tracing and from any resulting improvements/corrections.

d) Obtain confirmation/documentation from final airtightness testing that all requirements have been fulfilled. (This may possibly be done before expiry of the warranty period.)

3.4 Airtightness during operation stage

During the life of the building, the airtight layer is often inaccessible for inspection and maintenance, yet there are joints and structural components that may need maintenance or attention. If the building is extended or converted, or if new penetrations are needed, it will be necessary to ensure that the work is carefully performed, and based on careful design, in order not to destroy the airtightness of the building through unsuitable designs.

Procedure for maintenance of airtightness:

a) Check airtightness around penetrations (e.g. ducts into the roof space).
b) Check airtightness around window casements and frames and doors.
c) Note and investigate complaints concerning draughts or cold floors. These are often due to a non-airtight building envelope, and can generally be put right.

4. EXAMPLES FROM THE METHOD – REQUIREMENTS

The following are a number of suggestions as to how the developer might formulate requirements, who is responsible for fulfilling the requirements, and how the parties concerned should confirm that the requirements have been fulfilled. The developer can choose those suggestions that best match his ambition levels. Alternatively, the suggestions can be seen as starting points for formulation of other requirements. Just how the requirements for a project should be formulated depends on many factors, such as the choice of contract form.

The planning and design stage

Requirement no. 1: Appoint a person within the design organisation to be responsible for matters relating to airtightness.

Requirement no. 2: The aim of the design, in respect of airtightness, is to deliver the necessary conditions (supported by good quality of workmanship during construction) for ensuring that the building meets the airtightness requirement at a pressure difference of ±50 Pa. (Select one of the alternatives below.)

> Alternative 1: Maximum air leakage as specified in the energy balance calculations for the building *.
> Alternative 2: Air leakage through the building envelope not to exceed xx l/m^2s *

* Requirement 10 specifies how airtightness is to be tested, and must be stated together with the requirement governing maximum permissible air leakage. It can be important in some cases also to include a requirement that specifies the required airtightness between different parts of the building (e.g. between fire cells or apartments). See also Requirement 10.

Airtightness requirements for windows and doors can be specified separately. They might be required to meet, for example, Class 4 airtightness requirement in accordance with EN 14351-1. Class 4 permits a maximum air leakage of 3 m^3/hm^2 at 100 Pa pressure difference. (This information is given by the window/door supplier.)

Requirement no. 3: The aim of design is also to ensure the necessary conditions for continued airtightness during the life of the building, through appropriate choices of design details, materials and combinations of materials. It must be known or demonstrated, and documented, that materials such as tapes, mastics etc. are durable when applied to the materials to which they are intended to be applied. It is also important that their adhesion is good under the conditions to which they will be exposed (e.g. temperature).

Requirement no. 4: Designs for airtight buildings must clearly include, show and describe detailing (in the form of drawings and descriptions), such as:

- How penetrations, leaks and holes in the airtight material can be avoided.
- How penetrations through the sealing layer should be made, where they cannot be avoided.
- In lightweight structures: how joints in the sealing layer are to be made.
- Connections around windows, doors and access hatches to roof spaces.
- Connections between joists etc. to the building envelope.
- Connections between outer walls / roof structure.
- Connections between tie beams / sloping roofs / braced walls.
- Connections between lightweight structures and concrete structures.
- Connections between steel structures, pillars, glulam beams etc.
- Connections of prefabricated elements.
- Structures in contact with the ground.
- Particular jobs and feasibility / method of construction to be agreed with the contractor.

The construction stage

Requirement no. 5: The contractor must appoint a person responsible for the building's airtightness. He/she will manage the work needed to ensure compliance with the requirements, be responsible for the contractor's testing, and prepare and submit documented verification to the developer.

Requirement no. 6: Startup / **work planning** must be performed where specific tasks for airtight buildings are being planned in conjunction with the designers. An **own inspection plan (airtightness testing)** of technical features and workmanship must be prepared.

Requirement no. 7: Training of personnel at the site (construction, electrical, ventilation, HVAC personnel etc.) to be carried out in connection with start of work.

Requirement no. 8: Results from own inspections of technical solutions and jobs to be documented. The documentation must also describe how problems, defects, etc. have been dealt with. In the case of general defects, all persons concerned on the site must be informed.

Requirement no. 9: Performance measurements and leak tracing must be carried out at an early stage, as soon as the airtight layer or membrane has been applied and fixed, and when no further holes will be made in it. The need for repairs or improvements must be decided. The results are intended to document that no local leaks can cause future problems as a result of the positions and size of leaks. (Depending on just where leaks are, they can cause problems such as draughts, inward leakage of ground radon or local moisture problems in roof spaces.) For large buildings, parts of the building can be completed and airtight-tested at an early stage. Airtightness must be better than the requirement as set out below. Measurements must be made in several areas, as specified by the developer.

Requirement no. 10: Verification measurements must be made when the building envelop has been completed, and must fulfil the airtightness requirement at ±50 Pa pressure difference.

> **Alternative 1:** Maximum air leakage as specified in the energy balance calculations for the building .
> **Alternative 2:** Air leakage through the building envelope not to exceed xx l/m^2s

Verification in small and large buildings: Test airtightness in accordance with EN 13829:2000, and report the results at least x days before the date of final inspection of the building.

Requirement no. 11: Repeat the confirmatory airtightness measurement as specified in Requirement 10 when the building's guarantee period expires, in order to confirm that the airtightness performance has not declined. The developer may also wish to consider including a requirement or conditions for monitoring the performance after a certain number of years.

Requirement no. 12: In the event of any changed methods, the contractor must show that airtightness requirements are being fulfilled, and that no other requirements have been overlooked.

CONCLUSIONS

If function and performance requirements have been properly formulated, and the physical production process is quality-assured, conditions are favourable for achieving an airtight building. The routines and checklists provide a means of applying the knowledge and experience from research and development projects to practical use.

ACKNOWLEDGEMENTS

The project has been financed by SBUF and FoU-Väst.

REFERENCES

[1] Sandberg PI, Sikander E, 2004, *Airtightness in the building process* (in Swedish), SP Rapport 2004:22
[2] Svensson O, Hägerhed Engman L, 2009, *Förbättringsmöjligheter av lufttätheten i byggnader – erfarenheter och exempel från lufttäthetsmätningar* (in Swedish), Nordic Passivhouse Conference, Gothenburg, april 2009
[3] Wahlgren P, 2010, *Goda exempel på lufttäta konstruktionslösningar* (in Swedish), SP Rapport 2010:09
[4] Sikander E, 2010, *ByggaL – method for ensuring airtight building envelopes*, SP Rapport 2010:73